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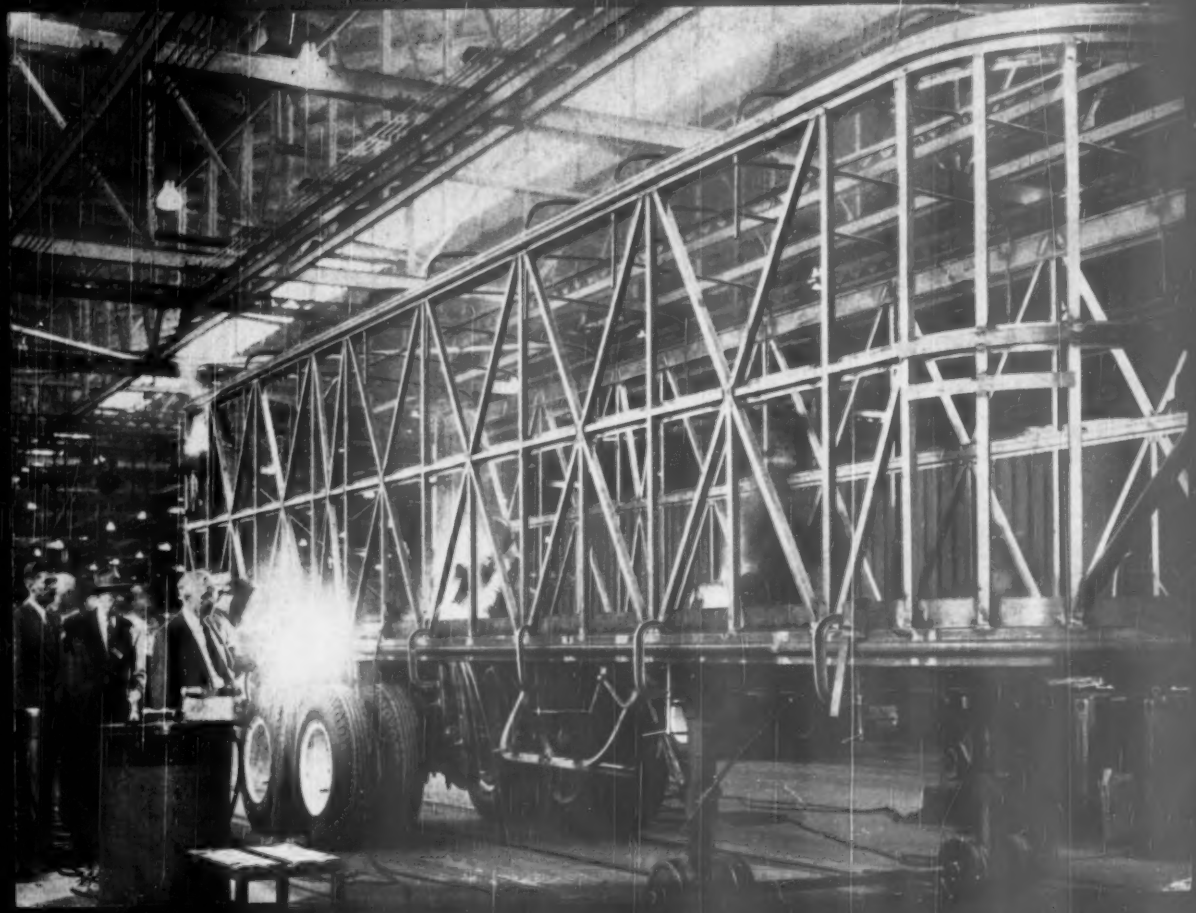

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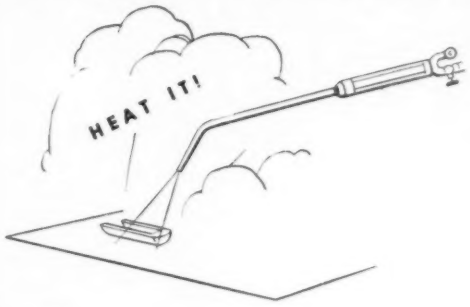

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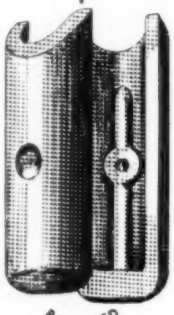

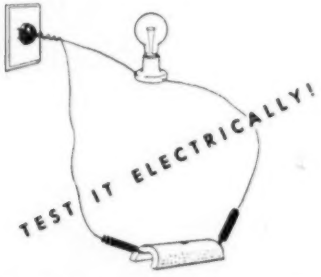

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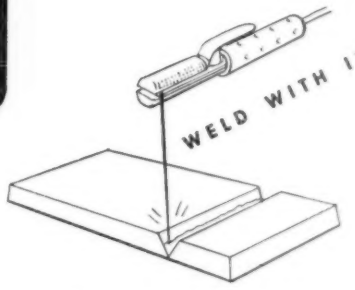

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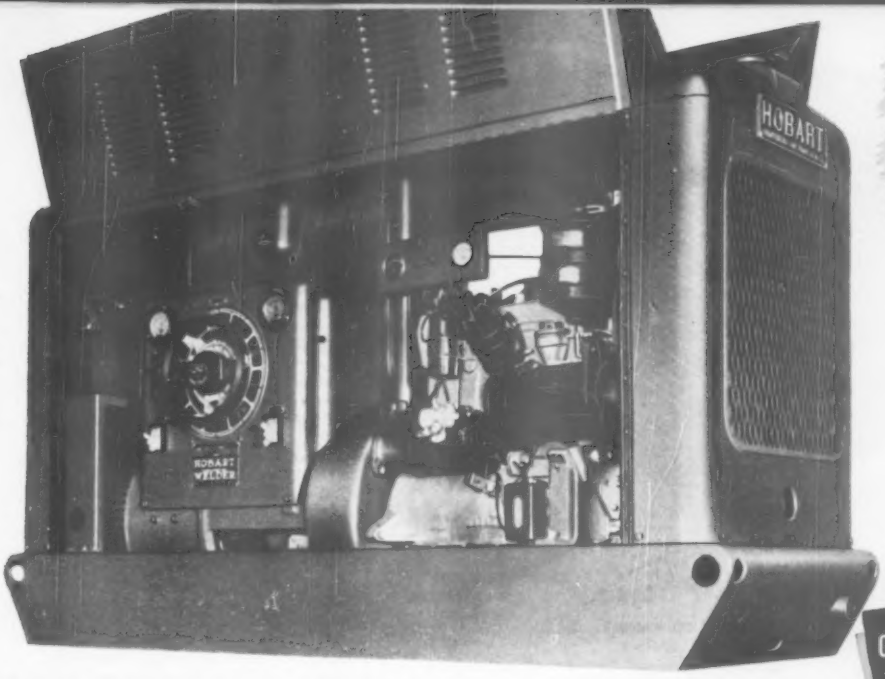

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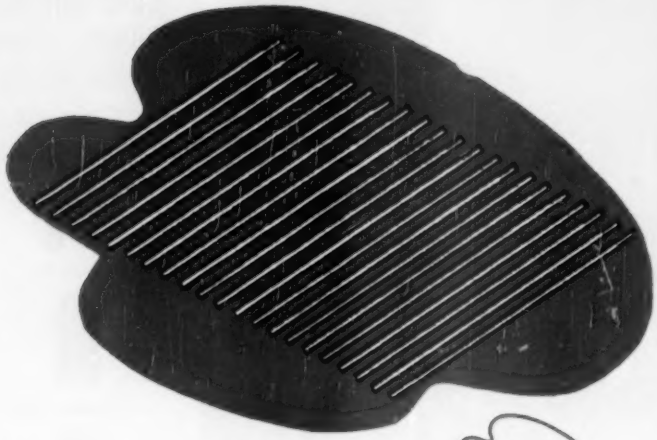

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Published monthly by the American Welding Society. Publication office, 20th and Northampton Streets, Easton, Pa. Editorial and general offices, 33 West 39th St., New York 18, N. Y. Advertising office, 400 Madison Avenue, New York 17, N. Y., Telephone: Plaza 3-4466. Subscriptions $5.00 per year in United States and possessions; foreign countries $7.00. Single copies, non-members $.75; special issues September and October $1.00; members 75 cents. Entered as second-class matter January 5, 1932, at the Post Office at Easton, Pa., under the act of March 3, 1879.

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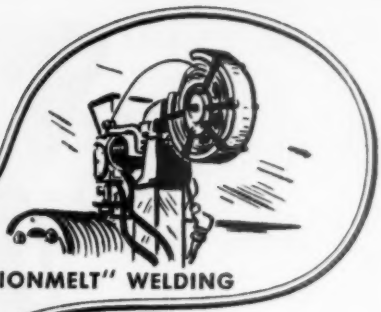

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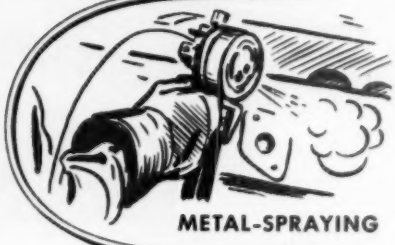

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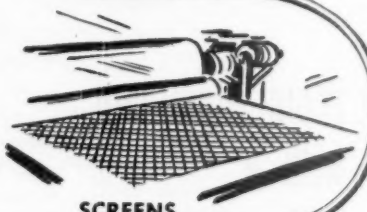

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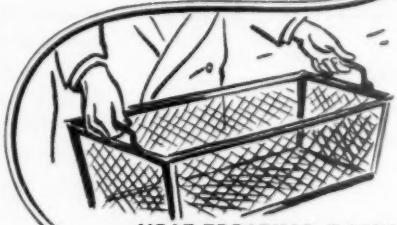

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The WELDING JOURNAL

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Importance of Design to Tanks and Pressure Vessels

Sound engineering design of pressure vessels cannot be assured solely by applying code formulas. For extreme services the designer needs to know more about stresses and strains in critical areas and the characteristics of many kinds of steels which may be used

by Walter Samans

SUMMARY

THIS paper, after an introductory presentation on the developments in the Unfired Pressure Vessel Code as an offshoot from the Boiler Construction Code of the A.S.M.E., aims to show that sound engineering design cannot be assured solely by applying the formulas given in the Code.

The rapid development in new uses for pressure vessels because of the growth of chemical processing and the resulting demand for extreme temperatures and pressures beyond the range of most steam-boiler designs has called the attention of the designer to the need for his better knowledge of the characteristics of the many kinds of steels to be used. Such data are only partly covered in material specifications because these are too general.

The technological problems involved add greatly to the required duties of the pressure vessel inspector, and attention is called to the control now exerted by the engineers in many large industries of the design, construction and inspection of pressure vessels built under these more complex rules.

There is included a general analysis of basic principles behind the relationship of load distribution vs. stress concentration at abrupt changes of shape in the vessel wall and around opening reinforcements of all sizes, and at the attachment of supports for external loadings on the vessel or to carry the weight of the vessel itself.

The closure is a special reference to one form of vessel which may fail due to elastic instability because of its unusual shape.

The Subcommittee on Unfired Pressure Vessels of the Boiler Code Committee would like to have readers of this paper forward all formulas and design data not now in Section VIII, 1950 Edition, which they believe should be included.*

INTRODUCTION

Several years ago, the author was asked by a structural engineer why the A.S.M.E. Code for boilers and pressure vessels had to be so frequently revised and why it was necessary to hold monthly meetings of the Boiler Code Committee to take care of questions on the Code that came in. The inquirer said he had in mind the longer time which existed between revisions of structural codes and other building codes in general without requiring such frequent interim meetings. His question just emphasized a generally known human failing, in that we may have our noses so close to the grindstone that we fail to realize that others' problems may be more complex than our own.

Structural engineering, although its design rules are always progressing to meet the need for larger structures, is seldom influenced by process operations. On the contrary, for steam boilers and unfired pressure vessels the increased use of chemical processing has resulted in both larger units in production capacity and increased operating temperatures and pressures. In fact, the development in unfired pressure vessels for use in processing operations exceeded the development of higher temperature and pressure ratings for boilers and superheaters.

This has resulted in placing in the unfired pressure vessel codes more extensive detailed information than many engineering designers, detailers, shop fabricators and inspectors have been accustomed to using within the limits of their training, and this applies as well to the author of this paper.

Just within the last two months, the secretary of one interested organization restated a feeling which is not new that the unfired pressure vessel code was becoming too much of a textbook in nature rather than the general guide that most of those concerned with unfired pressure vessels required. No doubt he had in mind the Proposed Revision of Section VIII of the A.S.M.E. Code[1] in which Appendices provide the rules for the design of other than simple vessels of shipping sizes. These added rules are purposely excluded from the main text because of the greater complexity of the formulas. Unfortunately, from the designer's angle, this is only a part of the story, because the safe design of many unfired pressure vessels as they are now needed for processing, takes in much more territory than can be covered by present code formulas alone.

DEVELOPMENT OF CODE

The few limitations placed on the first

Walter Samans is Chairman, Subcommittee on Unfired Pressure Vessels of the Boiler Code Committee, A.S.M.E., and Past Chairman, Pressure Vessel Research Committee of W.R.C. He is Consultant for the Sun Oil Co., Philadelphia, Pa.

Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

* Address the Secretary, Boiler Code Committee, American Society of Mechanical Engineers, 29 W. 39th St., New York 18, N. Y.

writers of a separate code for unfired pressure vessels over 25 years ago, included the application of material specifications and design rules much like the rules for boiler drums, plus fabrication and inspection requirements basically within the discretion of the inspector These had in mind comparatively simple tanks which were considered safer than boilers. Because of but few cycles of temperature change with no applied radiant heat, and not fully cognizant of the corrosion problem, the first edition of the new code seemed quite simple. It was prepared under the sponsorship of the Boiler Code Committee of the American Society of Mechanical Engineers as Section VIII of the Boiler Construction Code. Its first publication in 1925 was followed by revisions, which are now made about every three years, with changes in the interim covered by Addenda sheets issued annually. The latter are based largely on interpretations requested by reason of improvements in the manufacture of materials and methods of fabrication.

The one improvement in the construction of pressure vessels which indicated greatest progress was the joining of parts by welding, particularly electric-fusion welding which dates back only about 20 yrs. Since then, the need in chemical and petroleum processing for many varieties of alloy steels which have little use in boiler construction has added the task of writing adequate specifications into the pressure vessel code, to cover the fabrication methods and heat treatments required.

The wide range in sizes of vessels to be made, and therefore the thicknesses and special applications, have developed new methods of fabrication not now fully covered, even in the new code.[3] The largest pressure vessels, not including penstocks, water conduits and oil pipe lines, are aeronautical wind tunnels. One unit may embody well over 1200 tons of steel in its pressure parts and cost at least $500,000 for the bare vessel before adding any extraneous expenses for supports, housing and accessories. Many processing vessels cost from $50,000 to $100,000 each.

NEED FOR MORE RESEARCH

In the descriptive material which follows, particularly in the examples given, there are references to ductility vs. brittleness of steels, plastic deformations and residual stresses that may result. These are not given with the intent of adding to the complexity of wording in the construction code, but merely to indicate here how strain and stress measurements on most pressure vessel research projects, such as have been in progress at Purdue[5] and Lehigh[6] Universities for over 2 yr. under the sponsorship of the Pressure Vessel Research Committee, are very necessary for proper stress analysis. They more clearly indicate the need for improved design studies rather than a justification for the application of more exact formulas to all pressure vessels built for moderate pressure and temperature operation.

When to results of room temperature tests there are added the possible effects of temperature fluctuations in service, with temperature differences existing through sharply curved parts of pressure vessel walls already under elastic strains, the impossible task of providing practical formulas to cover such items in a pressure-vessel code can be realized.

NEED FOR MORE ENGINEERING

It is not the author's purpose to overemphasize herein the deficiencies in present Code requirements, but rather to point out to the designers, and to their supervisors, that conformity to the simple formulas which even the latest additions to the Pressure Vessel Code will contain will not always assure safe designs for all kinds of service conditions. Emphasis is placed, however, on the need for having complex pressure vessels, built for process temperatures below −20° F. or above 650° F. and all those using alloy steels, designed by men familiar with more than the simple dimensional problems involved.

In placing this requirement on designers, reference to the responsibility of shop fabricators and inspectors on materials, shop or field construction and testing is purposely omitted. While they must carry out rules into practical construction, it has become quite usual for pressure vessel engineers in industry, and particularly those in large organizations having a staff of engineers of varied training and experience, to regularly cooperate in formulating not only complete specifications and in supplying design drawings bearing all the essential directive notes thereon, but also to exert a check on their own company's shop and field inspection. When vessels are built subject to legal requirements, their activities supplement the work of official state or city inspectors, and usually also that of insurance inspectors. At the same time, the company inspectors obtain a familiarity with the vessels so inspected to aid their later inspection of these vessels in service. In considering inspection practices, all agencies should be given their proper share of credit.

MECHANICAL PROPERTIES VS. SERVICE NEEDS

This is not a paper on the relation of yield strength to fracture or ultimate tensile strength and how designs might be bettered in the case of higher strength steels as compared to mild-carbon steels. Neither is it to include a discussion on the economic factors to be considered when resistance to corrosion or an extreme of high or low temperature is paramount, involving the use of costlier higher alloy steels; nor is it to advocate the use of higher stresses where actual tests of materials in their condition in the finished vessels seem to warrant higher unit stresses in design. All these questions have been raised by users and manufacturers with regulatory and code authorities. They receive a mere mention here only to point out that higher service stresses impose a need for greater care in streamlining details of design and for taking advantage of knowledge gained from applicable test data.

The difficulty of correlating test data to permit more accurate designs casts doubt on the suitability of materials selected on the basis of such data for specific service in pressure vessels.

To complete a necessary reference to the quality of materials used with relation to their specified characteristics under acceptable code specifications, the author refers designers of pressure vessels to a series of lectures presented under the title of "Strength of Metals under Combined Stresses," by Dr. Maxwell Gensamer.[4] Some of the statements that follow seem to be substantiated by the experimental findings included in these lectures.

Without going into details, which can be assimilated more readily by the study of that publication, attention is called to one basic assumption that is practically true. It is that plastic deformation of steel which is isotropic does not change its volume.[4] Furthermore, in regions of equitriaxial stress in any mass of isotropic steel there is no plastic strain preceding failure. For anisotropic specimens, the nature of a fracture for such a test reflects the direction and amount of previous work.

NATURE OF STEEL FRACTURE

This leads to the speculative idea that under high biaxial principal stresses, the resistance imposed against distortion in an element of a pressure vessel is accompanied by some type of incipient internal shear failure in what is called ductile material The resulting reduction in area transverse to the principal stress is not dangerous enough to cause an early failure until it has progressed to the point where a simple calculation would indicate that the stress is far beyond the yield strength as determined from uniaxial tensile specimens. For static loading of pressure vessels, this is an assurance that limited distortion due to fabrication and the pressure test need not be feared. Still, all the more an effort must be made to prevent by more careful design any possibly excessive distortion which might take

place within narrow limits, and to minimize stress concentrations in vessels subject to pressure and temperature fluctuations that could produce a fatigue failure.

Because distortion is associated with the modulus of elasticity which for all steels is practically the same, one is apt to forget that there may be an incipient failure which is not primarily a tensile or a compressive failure but a progressive microscopic shear fracture as, for example, that preceding the appearance of a tensile crack on the face of a specimen.[4] To illustrate this, consider the necking type of fracture that usually occurs in a round-bar tensile specimen pulled at room temperature. It frequently appears to be a conical fracture which begins with a cleavage fracture at or near the center of the specimen where the greatest restraint occurs. Lower temperature or higher speed of load application reduces the degree of reduction in area before any fracture becomes evident on the surface. In every type of wide bar or plate specimen, and therefore most certainly in elements of pressure vessels, a reduction of thickness is accompanied by distortion in planes at 45° to the lines of principal stresses, and will be greatly localized at sharp re-entrant corners or projecting edges.

CYCLIC STRESS RANGES

Many treatises have been written on the phenomena of fatigue, and of these the larger number were intended to apply to the analysis of stress and strain in machine parts, which are generally operated under force fluctuations that result in high-speed fatigue types of failure. It is questionable how far fatigue phenomena, due to pressure variation only, enter into the strain-stress relationships of ordinary pressure vessels. Rapidly pulsating pressures are of another kind.

What is sometimes more important, in certain high-temperature operations where temperature differentials through the vessel wall are 100° F. or more, and where the frequency of temperature fluctuations may be as low as 35,000 annually, is that the vessel wall may crack in from 6 to 18 months. This is serious, as compared with no cracks in processing pressure fluctuations which exceed 100,000 to 200,000 annually. Thickening of the wall is not always the sole remedy. A change in shape or more efficient insulation may be the proper answer.

STRAIN IN ELASTIC RANGE

The amount of elongation permitted in a tensile specimen cut from the material as made and heat treated, if a casting or heavy-rolled plate, or if cut from the material as rolled for thinner mild-steel plates, is not the best criterion for determining the long-time safety of a pressure vessel in service. Whether the ductility of a steel is judged by elongation of test specimens, or the reduction of area, the figures cannot be an absolute measure for the condition in which the steel exists after the vessel is built. Also, because there are certain phenomena in the extension of specimens which are duplicated in test vessels, as exemplified in the Purdue tests[5] where there was a sharp corner or small knuckle transition between a cylinder and a conical head, it need not be necessarily assumed that the internal changes in microstructure are of the same pattern. For example, in a simple tensile specimen there might be a constant aggravation of microscopic shear fractures, while in a pressure vessel these may be accompanied by a change in shape as, for instance, an increasing radius of a knuckle accompanied by a shift of the neutral axis for the bent elements. The assumption of load by the adjacent plastically deformed metal in the hoop direction of the cylinder and cone, under the extra restraint may carry the load safely around the points where the initial microscopic shear fractures have taken place. It is interesting that in tests at Purdue, the maximum longitudinal stresses near the juncture of the cone and cylinder, within the elastic range under less than the design pressure, were found to be as much as two to five times the hoop stress simultaneously imposed on the cylinder.

The earlier mention herein of the Purdue tests did not refer to the difficulty of determining exactly what these stress measurements can reveal within such small volumes of anisotropic metal as are under unequal triaxial stress. This difficulty would still exist if the test vessels were much larger. These shapes prohibit the cutting out of specimens and slicing them to obtain measurements of progressive relaxation, as has been done on other simpler test shapes.

HYDROSTATIC TEST VS. DESIGN

It is on account of what some think to be almost unsolvable problems in seeking to correlate theories of metallurgy and stress analysis with practical uses of steels, that a hydrostatic test continues to be generally advocated for all commercially made vessels. Not only is this test, as carried over from riveted practice, and as supplemented by a hammer test which was first applied at a period when electric-fusion welds were more brittle, made to prove the effectiveness of the welding procedure and the welder's work but also to stretch plastically points of local stress concentrations, including the longitudinal welds and the girth welds. Its usefulness in corners, or at junctures and other sharp changes in shape or sections, depends largely on contour changes where concentrations of stress occur.

It is almost unnecessary to mention, except for record and as an aid to students, that imposed loads due to various types of attachments usually produce the highest combined stress in the vessel wall when the vessel is filled in the hydrostatic test at maximum pressure; the out-of-roundness in the wall will be less when the vessel is full of liquid under internal pressure, than when the vessel is partly filled with liquid, or under no pressure. For superimposed loads above the vessel, the attachments are usually most highly stressed when the upper equipment is imposing the maximum load with no pressure in the vessel; the details of direct load-bearing members can limit the maximum combined stresses. Designs should be based on the worst conditions in service and not necessarily on imposed loading that exists for a short time only during tests. The latter need be considered only in case a permanent set can occur during the hydrostatic test, which will leave the attachment in a weaker condition than before the test.

For related reasons, the designer does not take into account the 10% excess pressure allowed in the vessel when a relieving device is blowing at its designed flow capacity.

DESIGNERS' SKILL

In selecting the formulas in the unfired pressure-vessel codes, it was surmised that designers would be sufficiently competent to take care of details not specifically covered and those not subject to pressure loading. This assumes that they will be familiar not only with all types of such details and how they were economically fabricated in the shop, but also that they will have some understanding of how strain and stress are distributed when the most economical provision is made for superimposed loads. This presupposes a skill that the ordinary draftsman does not have; likewise, that the average trained engineer acquainted with another type of structure is usually equally familiar with construction of pressure vessels. This is generally not true, partly because of the tendency to copy details of design to save time, which may prove reprehensible on any but the simplest designs because the membrane stresses which are to be used in the code formulas, although providing for a so-called factor of safety to cover various unknown factors, should not be expected to offset gross crudities of design.

PRINCIPLE OF LEAST WORK

Nature performs its functions in the easiest possible manner or, in other words, with the least expenditure of energy. On this principle engineers have developed strain energy theories to analyze the changes in shape and the location and

direction of the principal stresses. Plastic models may now be used so that with polarized light the stress distribution can be visualized and recorded. This principle was once called the Principle of Least Work, now more often referred to as the path of least resistance. On that basis maximum forces tend to center in a plane that intercepts the shortest line between the course of load application and the center of gravity of the material that would normally carry the stress pattern if there was no discontinuity.

On a symmetrical shape—as, for instance, a symmetrically formed head attached to a simple cylinder, and assuming that stress relieving and radiographing have produced as perfect symmetry as is possible in character of material, thicknesses and uniformity in shape, the principal stress pattern follows circles concentric with the axis of the vessel and along meridian lines that are parallel to the axis of curvature and meet at the center of the head.

SHAPE VS. STRESS DISTRIBUTION

The above refers to the simplest shapes. Except for the discontinuity, the membrane formulas now in the code provide satisfactorily for heads under internal pressure. With heads of standard shape, a correction factor as a constant in head formulas provides adequately for discontinuity stress where the contours across the head to shell juncture are properly tapered. Internal pressure or external pressure on the vessel will then cause combinations of longitudinal direct stresses and bending stresses which are additive on the inside of the juncture whether there is internal pressure causing maximum tensile forces or external pressure with maximum compressive forces.

If a symmetrically formed head is attached to a cylindrical shell without a knuckle, the high stress concentration which occurs on the inner corner may under favorable temperature conditions result in plastic yielding without forming cracks, but adverse service conditions with a relatively small series of pressure fluctuations may start a crack, and therefore this type of construction is not generally permitted. The stress intensity obviously is a function of the thickness to diameter ratio. Although the research work done at Purdue was concentrated on a conical head, the theory in the stress analysis will apply equally well to other types of formed heads. The reason for using the conical heads in those tests was that the design of conical heads directly joined to cylinders was more controversial than the design for other types of heads. The simple formula now in use embodying the factor $1/\cos\alpha$ disregards that under elastic strains it is possible that the thickness of a conical wall of uniform thickness when there is a knuckle (element of a torus) might be made less.

Even though the proper details are used at the junctures of heads and shells and in other changes in shell shape, there are many other details which are in common use on pressure vessels which are designed largely by rules of thumb based on experience.

There is a general rule in Par. U-72(f) (1),[1] which reads in part as follows: "Except where specific details are permitted in other paragraphs, the design of welded vessels shall be such, that if bending stresses are brought directly upon a welded joint, the design shall be analyzed to keep the maximum stress within the allowable limits, and complete weld penetration through the thickness of the joined plates shall be obtained, with added fillet welds where necessary to reduce stress concentration." It grew out of a simpler rule which was originally added under the general heading of U-72 "Preparation for Welding."

This rule is really only a cautionary note, and therefore cannot be sufficiently directive, but the suggestion should be considered in designing opening reinforcement, supporting details of all types and large piping with questionable flexibility projecting from the vessel wall on which torque may be imposed in addition to bending moments.

The reinforcement around openings is a most common detail, and one that has received much attention from the engineer. Manufacturers of parts such as nozzles and manheads have generally considered the Code rules as requiring intelligent application, with the idea that approved fabricating practices can provide the necessary fillets or gradients in shape which will at least give some streamlining effect to the completed assembly on the vessel. Small parts are generally suitable because stress concentration, although localized at the attachment welding, is not excessive if the welds are of the minimum permissible size. The exception is on vessels intended for very low temperatures where more care should be used, depending upon the extreme of low temperature and the ductility of the materials.

SUPPORTS

Much has already been published on supports for horizontal cylindrical vessels, and as these are generally used for storage of contents at moderate temperature they offer few design difficulties, except in large field-assembled sizes. Saddle-type supports for thin-walled tanks and pressure vessels may be designed to advantage on principles for ring girders described by H. Schorer,[7] but in large vessels ring girders are preferred. For vertical vessels usually built for process operations, their height may bring in wind loads to a greater degree, and the general practice for larger vessels of considerable height is to apply a skirt of the same inside diameter as the shell, or to use a detail at this location similar to that shown in Fig. U-18(d).[1] When a marked temperature difference exists the upper edge of the skirt where attached to the knuckle is slotted to provide intermittent attachment. The practice of lapping the upper edge of the skirt past the knuckle that is over the head flange may be satisfactory for lighter and shorter vessels, and in that case legs or brackets should prove equally so. It is desirable that the head girth-to-shell seam weld be not covered.

On the application of formulas for skirt thickness required, refer to Timoshenko's "Theory of Elastic Stability,"[11] Articles 81, 84 and 87, the last named being included because the critical loading for a spherical vessel subjected to external pressure is shown to be theoretically the same as for a cylindrical shell under the action of uniform axial loading.

For very short skirts, when the length L of the cylinder is such that $(\pi R/L)^2$ is equal to or larger than $2R\sqrt{3(1-u^2)}/t$ there will be only one half-wave in the axial direction and the permissible maximum stress can be determined by a formula which is Euler's formula for an elemental strip: $S = \pi^2 E t^2/60\,(1-u^2)L^2$ with a maximum of 10,000 psi., in which t is the skirt thickness, E is the modulus of elasticity for steel, R is the skirt radius, and u is Poisson's ratio (usually taken as 0.3).

For greater length of the cylindrical skirt, the following formula,[12] which is independent of the length of the skirt, may be applied with 10,000 psi. as the maximum permissible stress $S = Et/18\,R\sqrt{3(1-u^2)}$. This formula may be written, without appreciable deviation, as $S = 1{,}000{,}000\,t/R$ and was first suggested by H. C. Boardman about 1939. When assuming what seems to be a practical skirt thickness, use the above formulas for a check.

The last two formulas are based on use of the stresses given in Table U-2 of Section VIII.[1] The added factor in the denominator is not 5 the "factor of safety" that determined the stress values, but includes an added factor between 3 and 4 because of a discrepancy from the theoretical formula found in actual tests on spheres under external load.

The results of these tests were reported in 1939 by von Kármán and Hsue-Shen Tsien,[8] as in agreement with previous tests on axially loaded thin cylinders to which the same formula applies. Their conclusion is based on the possibility of failure starting on a localized area denting inward and might be termed "dimpling."

Caution: In design, include wind effect and use special additional safety factors in areas subject to earthquakes.

OPENING REINFORCEMENT

Let us consider what is now in the Code

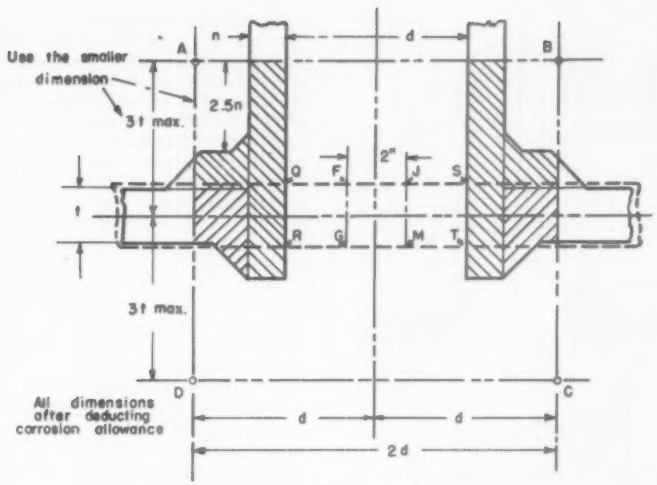

Fig. 1 Reinforcement limits for single openings

with relation to the reinforcement of openings. Paragraph U-59[1] states that there shall be a limited area in the longitudinal section of a vessel wall through the center of the opening, beyond which no metal may be considered as effective reinforcement, and leaves to the designer the actual distribution of the reinforcing material.

Near the inner edge around an opening, there is in addition to the nominal principal tensile stress some bending plus internal shear coincident with plastic yielding. Around large openings poorly detailed reinforcement may concentrate tensile deformation so close to a projecting edge that microscopic shear failure will accentuate the chance of tensile failure across the edge. This is one reason for rounding off all projecting edges.

On these limitations, shown in Fig. 1, it is recognized that for moderate sizes of openings, with finished opening diameter no greater than about one-third of the diameter of the cylindrical shell, there is no great error imposed in following these rules, except when the added reinforcement is entirely a nozzle neck projecting largely on the outer side of the vessel wall. Obviously, all computations for stress and sectional area are approximations but have been proved safe within the above limits. It is only when larger diameter openings are encountered that there may be harmful changes of shape.

In following this rule, extra reinforcement is provided around small openings which in most parts of vessels under pressure results in undue stress concentration at attachment welding. On large openings, it is generally recognized that under this rule much of the reinforcement may be too far from the edge of the opening and that the over-all shape should be streamlined.

LARGE OPENINGS

On some vessels openings of special shape may be required having critical diameters much in excess of one-third the vessel's diameter. In such cases the design engineer has to use his own judgment in providing an adequate amount and distribution of reinforcement. Although these variations are known to occur, they are not mentioned in the present pressure vessel code.[1,2] As one result of actual experiences, a major Proposed Revision of the A.S.M.E. Code Section VIII[3] will cover these conditions for design more adequately, although not fully.

When openings are very large compared to the diameter of the vessel, it is desirable that more thought be given to the shape of the added cross section. The location of reinforcement in the transverse section of the opening may become as important as that which is parallel to the longitudinal axis of the vessel. Paragraph UA-7, which is added in an appendix of the Proposed Revision of Section VIII[3] only generalizes on this design. Besides the ratio of finished opening diameter to vessel diameter, the ratio of thickness to vessel diameter is also important. This is the total thickness around the opening after the reinforcement is added, and in case of plate reinforcements will help to set the outer limits of metal that take up a material part of the loading.

Under some conditions, it is desirable to thicken both the vessel wall and the nozzle neck, when that simplifies the design and the vessel is required to be stress relieved in any event to avoid severe residual stresses. In other cases, and usually because it is difficult to vent vapor from a horizontal vessel past inward projecting reinforcement when the operations require this, it is desirable to have plate reinforcements placed directly against the outside of the vessel wall, and to provide in the nozzle neck only a minor part of the total reinforcement area required.

On openings that are the same as the vessel diameter—or say more than 85% of the vessel diameter—it is necessary to consider distortion across the transverse section of the branch or nozzle opening, which will impose severe bending stresses in the vessel wall if not provided for in the design. Buckling may occur in the vessel wall opposite to the opening, unless it is reinforced, and simple calculations for axial forces due to internal

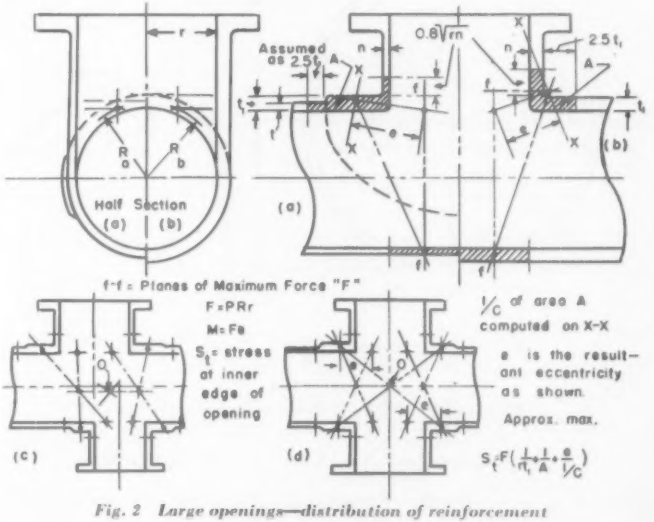

Fig. 2 Large openings—distribution of reinforcement

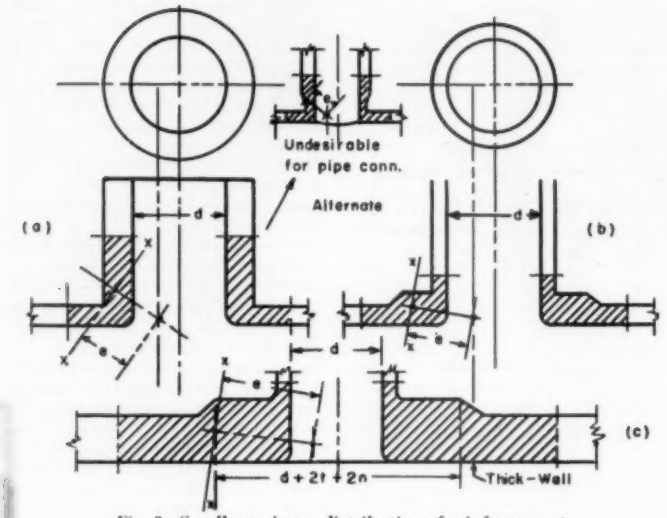

Fig. 3 Small openings—distribution of reinforcement

for external pressure against the resisting moment of the critical section are readily made. See Fig. 4. A considerable amount of data on large branch openings for piping, which is useful for design of large nozzle openings not perpendicular to vessel wall, was published in 1946.[10]

DEGREE OF STRESS CONCENTRATION

The following approximate method may be used to determine for comparisons of shape the maximum tensile stress in the reinforcement. It is applicable to openings in pressure vessels that are larger than about one-third of the vessel's diameter. This method is not intended to be a substitute for test data or mathematical stress analysis.

Figures 2 (*a*) and (*b*) show an outlet of the same diameter as the vessel. In a pipe tee it has proved safe to double the required design thickness of the wall all around. By the suggested criterion of the plane of maximum force, it can be shown in this example that although the resultant eccentricity (*e*) between the plane of force and the center of gravity of the effective area (*A*) is less in type (*b*) than in type (*a*), the maximum stress on the inside edge of the opening is about 40% higher. The graphic method and formulas shown in this figure give the approximate maximum tensile stress.

In the case where two directly opposite large openings form a cross as shown in Fig. 2 (*d*), or where two openings are not directly opposite and one is smaller than the other but in which the reinforcement in part is common to both as shown in Fig. 2 (*c*), the planes of maximum force will enclose the weakest part of the vessel wall centering at (*0*), and the most effective distribution of the common reinforcement should back up this area.

Relatively small openings are shown in Fig. 3. In walls of moderate thickness, a thick-walled nozzle may be favored as shown in (*a*) rather than a plate or flange against the shell as shown in (*b*).

The approximate computation indicates a smaller eccentricity for the thick neck, and there a larger area enters into the section modulus. Therefore (*a*) may be preferred to (*b*). An alternative to (*a*), as shown, may have still better stress distribution but if it is a pipe connection it may break off in service.

Sketch (*c*) shows a proposed distribution under Par. UG-40(d) (2)[3] which is quite favorable, as compared to the extremely heavy welding at the boundary of reinforcement on present limits.

In case of openings larger than one-third of the vessel diameter, under which consideration must be given to the application of Par. UA-7[3] in the Proposed Revision, Fig. 4 indicates that concentration of the reinforcement near the nozzle neck is desirable, but more so in the case of thin-walled vessels. The criterion for maximum S_z (last formula under this figure) will seldom be needed; a large opening in the underside of a large horizontal vessel for low pressure, located near midway between supports, is one example.

In all these examples, the pressure in the vessel constrains the direction of the forces to follow around the curvature of shell in the shortest path on the principle of least work. The tendency is to adhere to the line of the plane intersecting the assembly, as indicated, and reinforcement so shaped as not to have the center of gravity in any cross section close to this plane just introduces that much eccentricity producing some added secondary stresses. When the vessel wall becomes thinner, there is more distortion around the opening because of such eccentricity with relation to the shell diameter. In thinner shells in relation to any diameter, there being less restraint, the part of the shell section adjacent to the opening will carry less load beyond the borders of the attachment of the nozzle or opening reinforcement, whether the latter is an

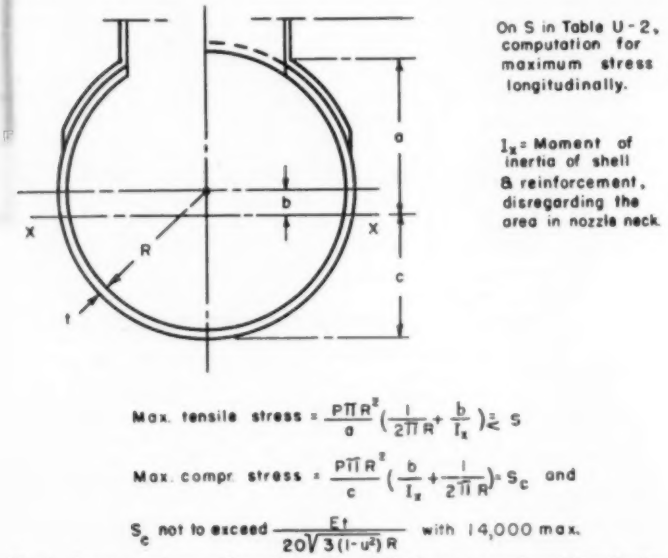
On S in Table U-2, computation for maximum stress longitudinally.
I_x = Moment of inertia of shell & reinforcement, disregarding the area in nozzle neck.
a
b
c
R
t
X
X
Max. tensile stress = $\frac{P\pi R^2}{a}\left(\frac{1}{2\pi R}+\frac{b}{I_x}\right) \leq S$
Max. compr. stress = $\frac{P\pi R^2}{c}\left(\frac{b}{I_x}+\frac{1}{2\pi R}\right) = S_c$ and
S_c not to exceed $\frac{Et}{2.0\sqrt{3(1-\mu^2)}R}$ with 14,000 max.

Fig. 4 Large openings—effect of vessel's wall thickness on preferred distribution of reinforcement

applied plate or an extra thick neck without a plate.

Approximate stress figures for the maximum stress inside the edge of the opening can be based on the moment of inertia of the section that may partake in the stress distribution, and in that case, rather than 2.5 times the nozzle neck thickness, this effective length of nozzle may be taken as $n = C\sqrt{rt}$ in which r = inner radius of neck, t is the thickness after deducting corrosion allowance, and the constant $C = 0.6$ or 0.8 depending on whether the nozzle neck or the assembly to which it is to be attached is the thicker. In the case of heavy-walled vessels, this refinement may not be warranted.

LARGE OPENINGS UNDER EXTERNAL PRESSURE

On extremely large openings for vessels designed to be subjected to external pressure, reinforcement distributed for internal pressure only may not be of the best form for also resisting the external pressure. Except in the case of jacketed vessels, a perfect vacuum is the maximum possible external load and as the internal pressure in design usually provides for a minimum test pressure of 25 psi. and sometimes more, the effect of alternating pressure loading should be considered, especially the Bauschinger effect which is a greatly reduced yield strength under one stress (tension or compression) following the application of a stress beyond the yield point of opposite sign which will weaken the steel against further reversals of stress, and may lead to a form of fatigue failure. Several methods of applying reinforcement for such conditions that have been successfully used are shown in Figs. 5 (*a*), (*b*) and (*c*). They should be applied with judgment, depending upon conditions for each case. Gussets to brace such shapes are not preferred to other more uniform and symmetrical arrangements, because at the ends of such gussets the welds may be subjected to high stress concentrations, and particularly for continuously reversed loadings in operation are these objectionable.

OPENINGS IN WALLS HAVING DOUBLE CURVATURE

With respect to openings in heads except in spherical surfaces away from knuckles, the maximum forces occur across meridian lines. In any place on a hemisphere, wholly clear of the shell girth weld, and in at least the middle 50% of the area for a dished head, stresses for a circular opening wholly within such areas are assumed to be symmetrical.

Where an opening passes through the knuckle of a dished head or within the smaller radii of an ellipsoidal head, the maximum computed stresses should include bending stresses superimposed on the membrane stress, and the maximum

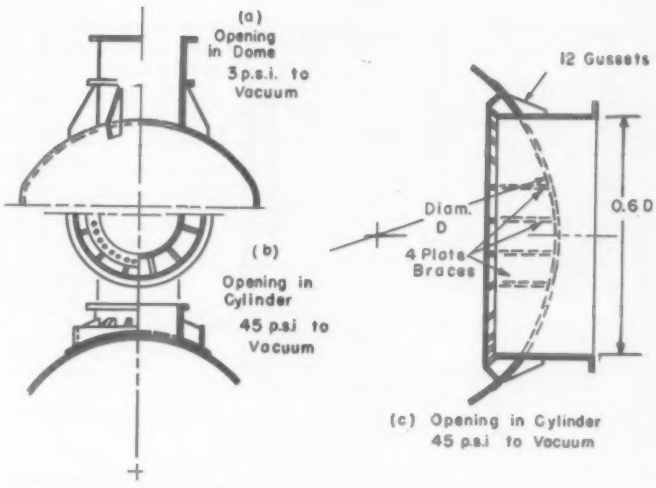

Fig. 5 Large openings in vessels subjected to external pressure

total stress may not be across a meridian line. Unreinforced openings are, of course, not permitted in such locations. See Fig. 6.

In connection with jacketed vessels subjected to external pressure, these are usually within shipping sizes and therefore are shop-made. A number of problems of different kinds, and sometimes quite complex, arise in this field. See Figs. 7 (*a*), (*b*) and (*c*). Sometimes the main vessels have both an inside and outside pressurized jacket, depending upon the spread in extreme temperatures needed in the process operation, and the higher rate of production cycles which can be accomplished by using this form of jacketing. Occasionally a heating or cooling medium is applied through a series of coils inside the vessel, in addition to having a pressurized jacket on the outside. A bottom outlet nozzle from the inner shell may pass through a stuffing box in the outer shell, in which case the jacket pressure is assumed to act over the full area of inner and outer heads. In a case where such a bottom outlet nozzle is rigidly connected to both the outer and inner shell at the center of the head, it is customary to assume that only two-thirds of the jacket pressure acts against both the outer shell and the inner shell. The connecting opening neck is designed to support one-half of the pressure over the total projected area of the head. Both assumptions are on the safe side.

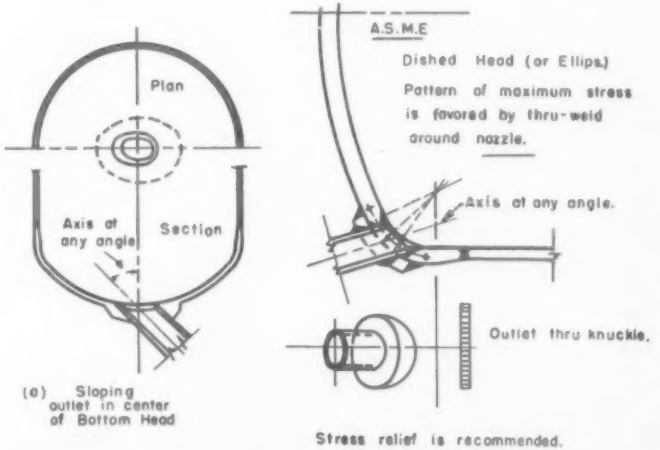

Fig. 6 Openings through heads at locations of sharpest curvature

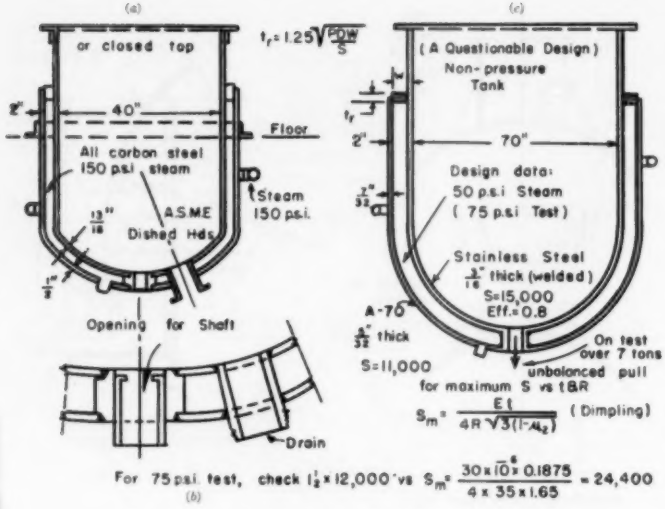

Fig. 7 Openings through walls of jacketed vessels

Of course, the pressure, if any within the inner shell, is discounted as the jacket may be under pressure while the vessel is opened to atmospheric pressure. In case there is a possibility of vacuum in the inner vessel, this should be included in calculating the effect of the jacket pressure.

An example of a collapsing failure in a jacketed vessel under test came up within the last year. The inner shell was bulged inward by the jacket pressure at one side of the bottom outlet which was built as a rigid connection, as shown in Fig. 7 (*b*). It is possible that the relative thicknesses of the inner and outer shells permitted an unbalanced deflection which tended to flatten the curvature of the inner shell sufficiently to permit the collapse.

LARGE FIELD-ASSEMBLED VESSELS

Because large field-assembled vessels intended for vapor or gas only will never have but a small percentage of contents as a liquid, it is usually considered uneconomical to design such vessels of sufficient strength, including supports and foundations, to permit a hydrostatic test. Extreme cases are gas balloons, which may be 50 ft. or more in diameter and several hundred feet long, and to a lesser degree wind tunnels for aeronautical tests. There have been cases where the cost of such a v essel could be more than doubled when the foundations and the vessel itself with its supports are designed for taking a hydrostatic test.

In the petroleum industry, it is customary to design all vessels intended to contain flammable liquid-petroleum products for a water load, and these can be hydrostatically tested, except for retests after an insulating lining is placed.

In the construction of special shapes, for vessels which are surfaces of revolution, and particularly in large field-assembled vessels, it is possible to use a shell having double curvature in which the principal stresses lie in the meridian and latitude directions, in accordance with a well-known formula:

$$\frac{T_1}{R_1} + \frac{T_2}{R_2} = P \text{ or } T_2 = R_2\left(P - \frac{T_1}{R_1}\right)$$

where

T_1 = meridian force, in lb. per inch of latitude arc

T_2 = latitude force, in lb. per inch of meridian arc

R_1 = radius of curvature in the meridian plane, in.

R_2 = length of the normal (cone radius; that is, shell to axis of revolution), in.

P = internal pressure, psi.

This formula is assuredly safe in all cases for outward curvature only. It simply expresses the equilibium of inwardly acting forces, respectively along the meridian lines of the shell and perpendicular thereto along the normal, for any point in the wall with the corresponding radii of shell curvature, as opposed to the outward forces due to internal pressure. In a circular tank, and for any horizontal projection, T_2 is readily derived after T_1 is calculated from the equation of equilibrium of vertical forces above (or below) the horizontal section; that is, the level where T_1 stresses are required. For some reason, this formula does not appear in the pressure vessel codes,[1-3] although it should be there.

This formula may be used for design of gas storage "balloons" and spheroids of all types, of which many operate at a pressure of over 15 psig. In some cases, extremely large diameter vessels of generally spheroidal shape have been noded by internal structural framing to carry the reactions at the junctures of spheroidal segments. Any shell having double curvature will not always be in equilibrium, due to variable liquid head and any other changes in pressure distribution; any compressive forces produced thereby should receive special consideration.

Because of the weight and pressure for the larger structures of this kind, as compared to their diameter and plate

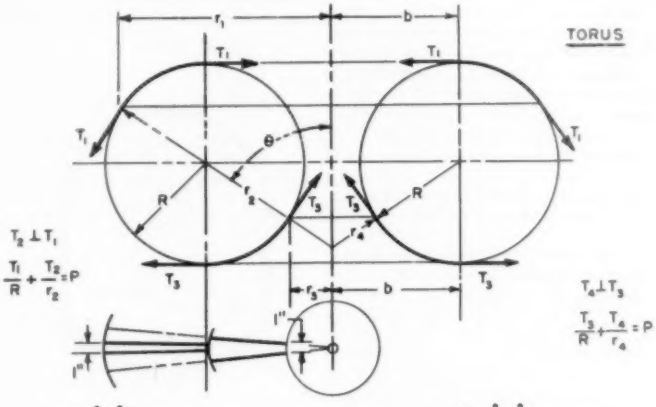

Fig. 8 Equilibrium in the elements of a toroidal shell

thickness, additional steel framing has been placed under and inside of the vessel wall, usually attached by welding. At present, the pressure vessel code does not fully cover such vessels, and because structural material is usually made to A.S.T.M. A 7 and partakes of the membrane stress, there is a question whether there should be a rule requiring the use of a carbon steel on which at least a carbon limit is reported, so as to assure its weldability.

Some of these large vessels are used in extremely low temperature areas, but fortunately when liquefied petroleum gases are stored, the vapor pressure is much lower under the low-temperature conditions than that for which the vessel is designed. This is covered by Par. U-142(a) (2) in the Code,[1] and in the proposed revision it has been worded as follows: "UG-66(d) (2). No impact test is required when the operating cycle is such that the pressure at −20° F. is less than one-fifth of the maximum allowable working pressure at 100° F."

To properly support large vessels weighted with liquid contents is a real problem, when they are not permitted for any reason to rest directly on sand cushioned foundations.

Although the design of supports and likewise lugs and brackets for superimposed loads is still left to the judgment of the designer in the major Proposed Revision of Section VIII, 1950 Edition,[2] a pertinent general caution appears in a note which follows Par. UG-29(e), and in Appendix G: "Suggested Good Practice Regarding Design of Supports."

BRACED COLUMN SUPPORTS

Because of some failures at attachments of columns to shells of large vessels, that have occurred under tests or during examinations involving a hydrostatic test, it is probably not necessary to show here details of the methods that have been used and are now used for the attachment of supporting columns to carry large vessels—the nature of the details depending entirely upon the size of the vessel, the thickness of the vessel wall and the weight of the material to go into the vessel under service requirements. A great deal of knowledge has been gained from experience, and tubular columns are much used.

It is normally expected that the hydrostatic test will impose stresses that are going to be at least 50% higher than those obtaining in service. If there is only internal pressure in service, the stress-strain curve never gets to the extremes of either the unloaded or the loaded condition imposed by the test, unless there is a complication in the method of support which induces other types of distortion than those due to pressure and weight alone. For instance, in a group of columns supporting a large vessel, the attachment

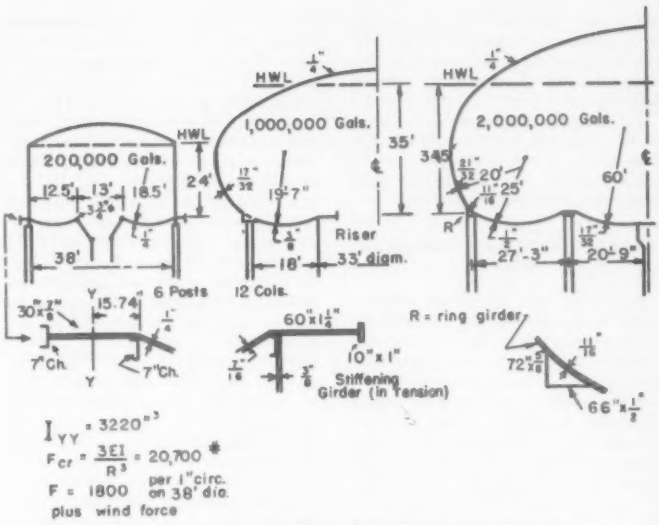

Fig. 9 Toroidal segments in bottoms of elevated water tanks

may be computed for the welding on an assumption of equal distribution, and on the assumption that a column will remain vertical.

On large, thin-walled vessels, there is bound to be a form of distortion which results in the horizontal section at the top of the supports no longer remaining truly circular, as designed, but possibly scalloped (bulged outward) between columns. In reverse, unless some method of support could be devised so that the columns would always be centrally loaded, there is the possibility that their tops will deflect inward, which accentuates the scalloped effect. The design should be such as to prevent an excessive amount of such scalloping and bending; lateral bracing and struts between columns are commonly used for this purpose.

In connection with large spherical vessels, L. P. Zick and C. E. Carlson[3] describe an investigation to determine the action of the column-to-shell connections of a new 48-ft. diameter sphere supported on 8 tubular columns. Electric strain gage measurements were made to determine the existing stresses induced by various water and gas pressures.

It was found that the tops of the columns move in under full water load and induce bending in the shell at the

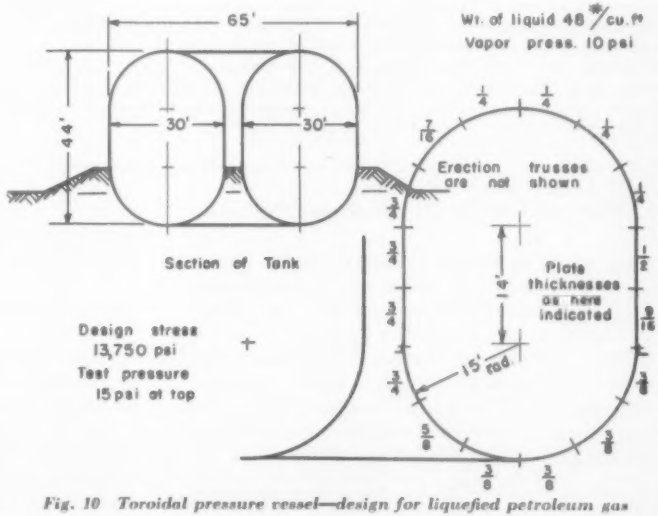

Fig. 10 Toroidal pressure vessel—design for liquefied petroleum gas

connection. These stresses are not directly additive to the gas-pressure stresses, and the gas-pressure load rounds up the shell and moves the tops of the columns back out.

Although the thickness of the shell plate at the columns is found to be somewhat conservative, it is recommended that the present practice of making this plate thicker than the others be continued.

LARGE VESSELS OF TOROIDAL SHAPE

In closing this subject of pressure-vessel design, there is one type of shape for a pressure vessel to which special attention is called, because it has been used mostly in segmental form in the bottom of elevated water tanks and seldom elsewhere. A caution seems pertinent in connection with such use, because of incomplete treatment in textbooks. This shape is a torus shown by Fig. 8. Types of water tank bottoms are indicated in Fig. 9. Figure 10 shows a design which was intended to contain liquefied petroleum gases under pressure. It was never built, as far as known, for economic reasons. It provides extra thickness on the inner side of the torus as shown, because of the compressive forces that exist there. It was proposed to support this pressure tank on a bedded sand-fill to be carefully packed around the base of the tank, in preference to using columns if so permitted.

For the theory, refer to Timoshenko's "Theory of Elastic Stability,"[11] page 216; "Strength of Materials, Part II," 2nd ed., 1941, page 218; and "Theory of Plates and Shells," 1st ed., 1940, page 366. By Fig. 145, the diagram in the last-named book does not analyze the stress conditions on the inner element of the torus at all, and that is the one where caution in design should be exercised.

In a complete shell of this shape there is no discontinuity, and a change of shape to accommodate unbalanced compressive stresses may occur naturally within permissible tolerance. However, at extremely low atmospheric temperatures, or for low-temperature contents, materials suitable for such conditions should be used. The use of such a shape for the bottom of a water tank does not expose the metal in the bottom to a much lower temperature than the temperature maintained for the water in the tank; when the tank is empty or nearly so, there is little or no load on the bottom.

It is pointed out that on the inner half of the annular segment of the torus, the force acting along a meridian line of the bottom which is the component of the vertical load across any inch in the horizontal circumference is bound to be greater than the load imposed on this same section by the internal pressure alone. Regardless of whether this pressure at any point considered be due to hydrostatic loading alone or augmented by a vapor pressure above the liquid, the difference, as determined by the formula of double curvature given above, is that part of the pressure which should be carried in compression by the annular elements on the inside segment of the torus. See Fig. 8. Inside of the annular segment of the torus, there can be a spherically dished segment and both supported by a circular girder, resting in turn on columns, or directly on some type of foundations if the tank be close to the ground.[9] Any unbalanced force between the horizontal components of the load imposed by the spherical segment and that from the inner edge of the toroidal segment can be carried in tension or compression in this ring.

The outer half of the annular toroidal segment of such a tank may be continued into a vertical shell by means of curved plates merging smoothly with a liberal radius, in which case the problem of the tank's support becomes mainly one of structural framing. If it be decided to carry the load from the outer edge of this toroidal segment to a ring girder which in turn may be connected to a vertical shell ring, the problem becomes less simple. The examples of water tank bottoms shown in Fig. 9 do not show this type of connection except in the case of the smallest tank shown.

There is one concluding statement which is warranted in the final analysis of what is important in design and construction of tanks and pressure vessels, and that is that failures may occur, not because of incorrect theories, but because not enough theory was applied to the design.

ACKNOWLEDGMENT

The author acknowledges the helpful criticisms of H. C. Boardman and E. C. Korten in the review of the original draft for this paper.

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Discussion by H. C. Boardman

This paper shows clearly that codes for pressure vessels are dynamic—are constantly evolving to keep pace with new knowledge, new material, new services and new design and construction methods.

Reference is given by the author to Herman Schorer's treatise on "Design of Large Pipe Lines" relative to saddle supports and ring girder supports. Perhaps the best published references on saddle supports for pipe lines and horizontal cylindrical vessels are:

1. "The Strength and Stiffness of Thin Cylindrical Shells on Saddle Supports," by Richard S. Hartenberg, 1941. Thesis submitted to the University of Wisconsin.

2. "Tests of Cylindrical Shells," by Wilson and Olson, *University of Illinois Bulletin No. 331*, dated 1941.

Neither Hartenberg nor Wilson claimed to have solved analytically the problem of saddle-supporting systems. Hartenberg concludes his work with the frank admission that: "It is the author's opinion that the evidence presented points to the conclusion that the problem of design stress in unstiffened thin circular shells on saddle supports is not amenable to mathematical methods but

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must be worked out in the laboratory by actual experiment."

In a parallel mood Wilson confesses that: "Unfortunately, no analysis has been developed for determining the width of the portion of the shell that is effective in resisting the circumferential moment."

There are unpublished experimental and analytical papers on this subject which should be "smoked out," among them one by L. P. Zick.

The author correctly states that the hydrostatic test, supplemented by the hammer test, not only is a proof test of sorts but is also a means of stretching plastically regions of local stress concentrations, including both the girth and the longitudinal welds. At and near discontinuities deliberately designed and built into a vessel such, for example, as a direct cylinder to conical head connection, plastic reshaping under the hydrostatic test, followed by release of pressure and a few cycles of service loading and unloading, may reasonably be expected to establish a residual stress system resulting in wholly elastic service behavior, provided the geometry will permit such a system. Nature does her best, in such cases, to save the vessel and the designer.

The writer believes that much can be done to simplify and improve the reinforcement around shell openings. Perhaps bar rings around holes can be so shaped as to be free of bending moments. In a flat plate containing a uniform unidirectional stress field a double parabolic bar around a double parabolic opening, with a compression member joining the intersecting branches, and with the axes parallel to the stresses, would be subject to direct stresses only. In a flat plate containing an equi-biaxial stress system, a circular bar around a circular hole would also be directly stressed. In a flat plate containing a biaxial stress field of twice the intensity in one direction as at right angles thereto, a $\sqrt{2}$:1 elliptical bar around an elliptical hole, with the major axis parallel to the larger stresses would be free of bending. These three cases are illustrated in Figs. 1, 2 and 3, respectively.

It seems obvious that, except for the disturbing influence of the nozzle neck and cover, the circular bar of Fig. 2 would function just as well in a sphere as in a flat plate. Would the elliptical bar of Fig. 3 function just as well in the cylindrical shell of a pressure vessel as in the flat plate of Fig. 3? This is an interesting question for if the answer is yes, then the simple elliptical bar type of reinforcement should suffice regardless of the size of the opening relative to the cylinder diameter.

However, in designing nozzles and manhole connections, there should be kept in mind the stress field induced in the shell by internal pressure, the stress field induced in the shell by the vessel loading and supporting system, and the service variations and combinations of these stress fields.

Mr. Samans comments on the fact that the soap bubble formula, $T_1/R_1 + T_2/R_2 = P$ does not appear in pressure vessel codes. It is because the codes were written

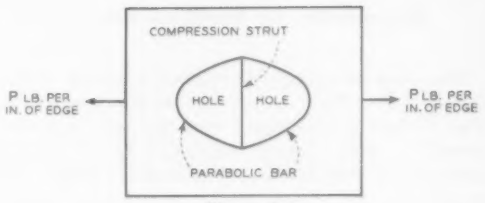

Figure 1

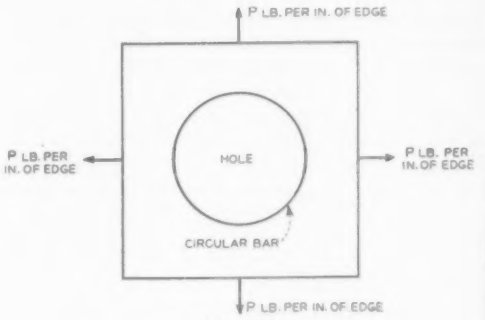

Figure 2

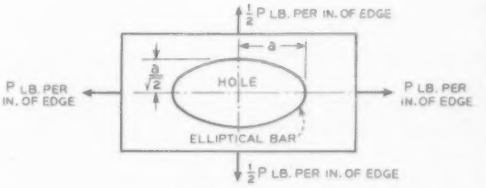

Figure 3

for shop fabricated vessels in which the hoop stresses caused by liquid head are so small relative to those caused by the design pressure as to be practically negligible. On the other hand, in large field-erected vessels the stresses induced by liquid head may dominate those caused by the design pressure; to such vessels the soap bubble formula should be applied, taking account of the superimposed stresses caused by the vessel-supporting system, wind, snow and temperature variations.

Mr. Samans has rendered a great service by impressing upon his readers the fact that the nominal stresses used in the simple design formulas of pressure-vessel codes bear only a caricature relationship to the actual working stresses in pressure vessels proportioned and built in accordance with the formulas. Incident to this revelation he has raised in his readers' minds the question: If vessels are safe when operating under generally low but locally high stresses would they not be safer if streamlined so that they would operate under higher general stresses and lower local stresses?

Discussion by Cyril O. Rhys

Regarding the structural engineer's remark as to changes in the Boiler Code occurring more frequently than changes in Structural Codes, this may be partly because a well-designed structure is much more a pictorial representation of the forces keeping it in equilibrium than is such a thing as a pressure vessel. Probably the most perfect example is a roof or bridge truss, a skeleton drawing of which is also a drawing of the directions of the forces which its members must sustain. This would tend to make design coincide with known methods of stress analysis, and would be in accordance with the simple beauty of Greek architecture. The use of only one structural principle (post and lintel) in the Parthenon, for instance, is an example of what I mean. Calculation then becomes very simple. The other extreme would be such a thing as a temple roof supported by statues of elephants standing on spheres, as in Indian architecture, and I think a complex pressure vessel would be nearer the latter than the former. Safety calculations would be neither simple nor easy to infer from the drawing as in the case of a truss. Incidentally the mosque of Santa Sophia is an architectural pressure vessel with its enormous and very thin dome. There is an article on this in the Encyclopedia Britannica, which might possibly be of interest.

I notice that Mr. Samans refers to the desirability of making design coincide with simple methods of stress calculation (Need for More Research). It would certainly seem that design should aim for shapes which will avoid complicated stress analysis. This is certainly done in machine design and tends to avoid complication in manufacture and computation. It is particularly true when temperature stresses occur in addition to the other loads.

The fact that triaxial stress in a plastic material with all stresses equal will produce no deformation is a point which I believe is often overlooked. It would account for a number of alloy-tube failures in which no strain is observable. I have come in contact with this phenomenon a number of times in the past. The usual explanation has been that all the strain is in the substance binding the crystals together and not in the crystals themselves, so that there is a very great strain confined to a very small area—all the strain is in the mortar and none in the bricks, was one way of putting it—but the triaxial effect may very well have been the real explanation. The Santa Sophia dome shows an interesting parallel to this.

Thickening the wall to take care of temperature stress is not only no remedy but makes the stress worse. This is for elastic material. In plastic material the temperature stresses often die out. R. W. Bailey discusses this at some length in his paper, "The Utilization of Creep Stress Data in Engineering Design." It appears that temperature stresses can be disregarded except for materials, such as glass and cast iron, where elasticity continues up to the breaking point. Experience with furnace tubes seems to confirm this.

Opening Reinforcement. At the edge of a hole in a very thin plate the greatest tensile stress is three times what it would be for uncut metal. The derivation for this is given in *Strength of Materials* (Arthur Morley) in an appendix. I have checked this by pulling plates with drilled holes in a testing machine, and the cracking off of the scale shows strains in accordance with the theory. The larger openings, to which you refer, would be very much the case of a hole in an infinitely thin plate. Some data published by the Taylor Forge and Pipe Works are in good agreement with the 3:1 ratio.

Not Enough Theory Applied to Design. I have had experience of two bad failures due to this—one where a rigid knee brace inside a vessel produced high-bending moments at right angles, and another where the necessary flexibility to take up temperature distortion (in this case relatively enormous) could easily have been provided for in the design on the principle that a helical spring wound up out of thin tubing is about the most resilient shape in existence. Calculation (when it was too late to do anything!) readily showed what might have been done.

Cyril O. Rhys, 160 Mountain Ave., Westfield, N. J.

Welding High-Nickel Alloys to Other Metals

Welding joints in dissimilar metals involving high-nickel alloys calls for an electrode matching the composition of the high-nickel alloy involved

by G. R. Pease and H. B. Bott

SUMMARY

A group of metallic-arc welded butt joints were prepared and examined for strength and ductility. The test joints numbered over seventy and included welds joining Monel, Inconel and commercial nickel to each other and to several other engineering alloys. This latter group included mild steel, 18–8 stainless steel in four composition ranges, 70–30 cupro-nickel, silicon bronze and Hastelloy "B."

The results indicated, in general, that the safest choice for welding joints of the type investigated is the electrode which matches the composition of the high-nickel alloy involved. Where two high-nickel alloys are involved, either matching electrode is satisfactory.

INTRODUCTION

With increasing frequency metal structures are being designed and built in which it is required that two metals of dissimilar composition be securely joined together. Dissimilar metal joints may be necessary, for instance, between two metals in a still or fractionating column where the corrosive nature of the vapor phase differs appreciably from that of the liquid phase. Dissimilar metal joints are also encountered in the construction of jacketed processing vessels, in the installation of applied tank linings and in the welding of clad metal structures. A common joint is one that occurs when steel supporting members are welded to an alloy tank or processing unit. Overlay welding may also be considered, in a sense, as a type of dissimilar metals welding.

There are several methods available to fabricators for obtaining joints between unlike metals. A partial tabulation would include at least the following: copper brazing, silver brazing, soft soldering, gas welding, several variations of fusion welding by electric arc and even mechanical joining. Each method has its own merits but metallic-arc welding with a consumable electrode offers advantages in utility and flexibility of operation that often dictate its preferred use. Unfortunately, however, there is a scarcity of useful data concerning the proper choice of electrode and properties to be expected of metallic-arc welded dissimilar metal joints. This applies to the high-nickel alloys as particularly as it does to any other similar family of metals.

SCOPE

The present data are limited to observations made in connection with the preparation and physical testing of fusion-welded joints made with commercially available arc-welding electrodes and regular grades of plate material. It is beyond the scope of this paper to elaborate upon the several available fabrication methods or to define their relative merits. It is also not intended to discuss the corrosion aspects of welded dissimilar metal joints.

The test joints fall into three general categories: (1) those in which commercial wrought nickel is one member, (2) those in which the 70–30 nickel-copper alloy known as Monel is one member and (3) those in which the 77–15–7 nickel-chromium-iron alloy known as Inconel is one member. Each of the three high-nickel alloys referred to above was joined to each of the other two and to each of the following metals: mild steel, 18–8 stainless steel (in four composition ranges), 70–30 cupro-nickel, silicon bronze and the wrought nickel-molybdenum alloy known commercially as Hastelloy "B."

Electrodes used in preparing the various joints included several high nickel alloy welding rods, three austenitic rods of the 18–8 general classification and a cupro-nickel rod. With the exception of the nickel-molybdenum type, all of the high-nickel alloy electrodes were those of one manufacturer. The austenitic electrodes were likewise from a single, but different source. It is recognized that there are several sources of electrode of either type, each with its own characteristics,

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Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

but the sheer bulk of the work involved precluded an evaluation of the properties and welding response to be expected of electrodes from additional sources. The austenitic rods were dip-coated; the others were all of the pressure-extruded type.

Of the high nickel alloy rods used, one was a rod commonly used for the welding of commercial grades of pure nickel, known to the industry as No. 131 and capable of depositing nickel modified only with sufficient alloying elements to insure adequate ductility and soundness. A second electrode, known to the industry as No. 132, deposits metal of the 77 nickel–15 chromium–7 iron or Inconel type and a third, known as No. 133, deposits metal of the 80 nickel–20 chromium type. This electrode and the Inconel electrode were subjected to a 500° F. baking treatment, superimposed on the as-dried rod, as a precautionary measure to insure complete weld soundness. In addition to the three already mentioned, there were two electrodes used which deposit metal of the 70 nickel–30 copper or Monel type. One of these, the No. 130-X electrode has been available for a number of years and can be recognized by its black, carbon-bearing coating. The other, the No. 140 electrode, was more recently introduced and can best be described as a low-carbon titania-type electrode. Both are in commercial use and each has its advantages over the other for specific applications.

The stainless electrodes included a straight 18–8 composition, a columbium-stabilized 19–9 composition and a molybdenum-modified 18–12 composition.

Although none of the test joints was prepared with any specific application in mind, many of them will be recognized as typical of joints encountered in present-day fabrication. With others, the Inconel-cupro nickel joint for instance, no practical application is immediately apparent but the knowledge that such joints are not impractical may eventually lead to some unique but useful combinations of materials.

TEST METHODS

The test weldment consisted of two pieces of plate, 5 in. wide by 10 in. long by $^3/_8$ in. thick, joined along the 10-in. edges. The joint was completed in five passes with $^5/_{32}$-in. diameter electrode. The bead sequence and other details are sketched in Fig. 1 and a typical weld cross section is shown in Fig. 2.

Weld quality was established on the basis of ductility and tensile strength measurements, with the conventional A.S.M.E. short-gage specimen being used for the tensile tests. In determining ductility, however, the transverse bend specimen could not be depended upon to provide a satisfactory measure of weld ductility. In most cases, a considerable hardness differential existed between the two plate materials. Also, the weld hardness was frequently higher than that of one or the other, or both, of the plate materials. Under these conditions and using the transverse bend specimen, a highly disproportionate amount of deformation would occur in the softer of the two plates near the weld or at

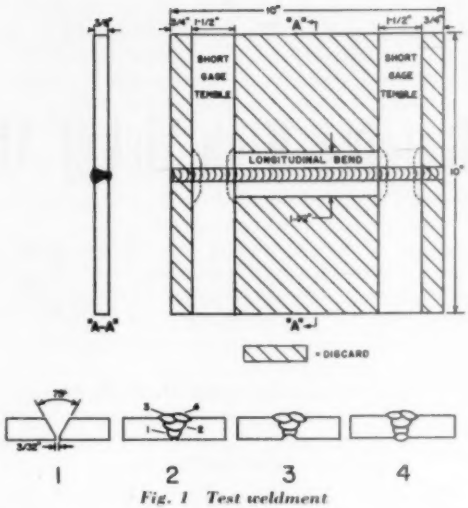

Fig. 1 Test weldment

the weld-plate interface. This resulted in premature failure in the plate material, ductile though it was, before the weld was distended to its limit. Thus, although the weld metal may have been capable of withstanding 30% or more of elongation it could not be so demonstrated and values of the order of 20% were obtained only with a great deal of manipulative difficulty. To circumvent this trouble the transverse test was abandoned soon after the test program was begun and a longitudinal bend-test specimen was substituted in its place. The results of transverse tests have been recorded, where obtained, but for the most part they do not represent the true ductility of the particular joints involved. It is probably safe to assume, however, that where no brittleness was detected up to 20% elongation in the transverse test, the joint was adequately ductile for most engineering applications.

Figure 1 shows the method of sectioning the 10- x 10-in. weldment to obtain the longitudinal specimen and also the two transverse tensile specimens. In testing the longitudinal specimen, bending was accomplished in two stages; first in a guided-bend jig around a $^3/_4$-in. radius mandrel and then further, if there was no failure at this point, under a compression head until flat or until failure. An arbitrary 1-in. gage length was used and failure was defined, as in the A.S.M.E. free-bend test, as the appearance during bending of any

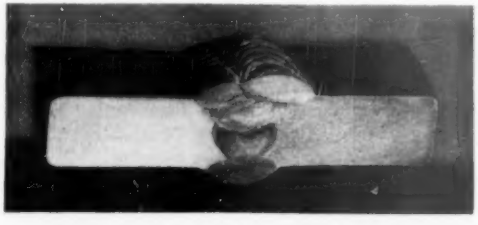

Fig. 2 Test-weld cross section

Fig. 3 Longitudinal bend specimen

defect greater than $^1/_{16}$ in. Figure 3 shows a longitudinal specimen bent to failure at about 45% elongation over the 1-in. gage length. This corresponds to about 55% elongation over a $^1/_2$-in. gage length. Figure 4 shows a transverse bend specimen which failed in the ductile plate material before the weld had elongated more than about 15%.

It is noteworthy at this point that a longitudinal-type bend test was considered and then adopted, apparently

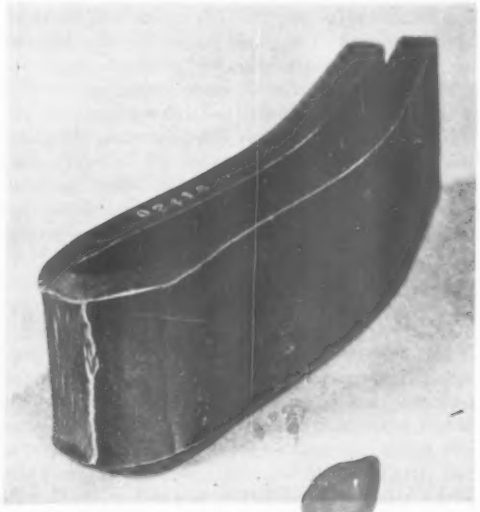

Fig. 4 Transverse bend specimen

for the reasons described above, as a means of evaluating weld ductility in two recent interpretations of the A.S.M.E. Boiler Code under Cases No. 896 and No. 1078.[1] These involved the welding of clad steels and of applied linings, respectively, where, in both cases, the weld metal is likely to be harder than the alloy cladding or lining material.

The usual precautions were taken with respect to cleanliness in the preparation of joint edges, with all traces of oil, dirt or crayon being removed with chlorinated solvent. There was no preheating or postheating, nor were any of the joints peened to provide relief from possible cracking tendencies. There was sufficient restraint upon the test plates during welding to prevent excessive warpage but the stress levels encountered in the welds were probably something less than those experienced in heavy construction. Arc blow was encountered in several instances, particularly where a considerable difference existed in the magnetic properties of the two dissimilar metals. This, of course, interfered with control of metal transfer and made it difficult to obtain as good bead contour as would otherwise be possible. Some relief from arc wildness was obtained by inclining the electrode so that it pointed slightly toward the least magnetic material and away from the direction of blow.

JOINTS WITH MONEL AS ONE MEMBER

In Table 1 are listed the properties of joints in which Monel plate is one member. Probably the most frequently encountered of the several types of joint composition is the one in which Monel is joined to mild steel. Flocke and Schoener[2] show the results of tests on arc-welded butt joints between these two metals, in which elongation values in excess of 28% were obtained along with 100% joint efficiency. The 130-X type of electrode was used to prepare these joints and still is being used in selected applications with practical results as satisfactory as these test results would indicate. However, experience has shown that when weld dilution by plate reaches some of the higher levels experienced from time to time in production welding, the resultant weld composition is prone to hot crack.

The mechanism by which cracking occurs has, in some quarters, been associated with the limited mutual solid solubility of copper and iron. However, more recently it has come to be appreciated that, whatever the reason for hot cracking, it can be eliminated over a much wider range of iron-nickel-copper compositions if the carbon is sufficiently low, than it can if the carbon is high. By high-carbon levels is meant something of the order of 0.25–0.35% and by low is meant anything up to about 0.10%. Having recognized the carbon effect, it was necessary only to provide an electrode which would deposit metal adequately low in carbon. Such electrodes are now commercially available and one of them, the No. 140 electrode, was used to prepare a Monel-mild steel test joint (Table 1). No great advantage for the low-carbon type of electrode is ap-

Table 1—Physical Properties of Dissimilar Metals Joints Involving Monel

Joint composition	*Electrode*	*Tensile strength, psi.*	*Joint efficiency, %*	*—Bend test elongation, %—* *Longitudinal*	*Transverse*
Monel to:					
Mild Steel	130-X Monel	66,000	100	..	38
	140 Monel	70,000	100	45	..
	131 Nickel	65,000	100	24	..
Type 304 Stainless	130-X Monel	83,000	100	..	37*
	140 Monel	83,000	100	45	..
	131 Nickel	84,000	100	..	25*
	18–8 Stainless	Weld cracked entire length			
Type 321 Stainless	130-X Monel	78,000	100	..	16*
	140 Monel	78,000	100	48	..
	131 Nickel	79,000	100	..	10.5*
	19–9 Cb Stainless	63,000	80	..	15.5
Type 316 Stainless	130-X Monel	83,000	100	..	34*
	140 Monel	88,000	100	44	..
Type 347 Stainless	130-X Monel	83,000	100	..	46
	140 Monel	82,000	100	48	..
Inconel	130-X Monel	82,000	100	46*	..
	131 Nickel	82,000	100	31	..
	132 Inconel	82,000	100	41	..
Nickel	130-X Monel	66,000	100	50*	..
	131 Nickel	66,000	100	46*	..
70–30 Cupro-Nickel	130-X Monel	59,000	100	49*	..
Hastelloy "B"	130-X Monel	83,000	100	42	..
	Hastelloy "B"	72,000	87	7	..
Silicon Bronze	131 Nickel	34,000	57	Nil†	..
	130-X Monel	27,000	45	Nil†	..

* No failure at indicated elongation.
† Failed in hot crack at weld-Si bronze interface.

parent from the results of these particular tests but, as mentioned before, weld dilution by iron is comparatively low in a simple butt joint. The effect of high-carbon levels in promoting weld hot cracking is more pronounced and more easily demonstrated when iron contents reach 30% or more as for instance, in overlay welding. Thus, while crack-free deposits are possible with the high-carbon type of electrode in the absence of more than a few per cent of iron, the low-carbon type is the preferred choice wherever the amount of dilution by iron is unknown or where it is likely to be high. Advantages with respect to operability in the vertical and overhead positions may dictate the use of the high-carbon type of electrode where iron base alloys are not involved.

In the welding of Monel to stainless steel with the austenitic stainless steel type of electrode, severe hot cracking was experienced which resulted, in one case, in a completely cracked weld and in another case in a weld which was low in ductility and joint efficiency. The difficulty probably stems from the fact that copper, picked up from the Monel, is tolerable up to only about 3% in stainless steels.[3] Thus, with only 10% of Monel in the weld the threshold level of 3% is reached and with 20% dilution the tolerable limit is exceeded by a considerable margin.

The Monel type of electrode is by far the better choice for this type of joint with the low-carbon modification again preferred to the high-carbon type because of iron dilution effects. Under most conditions the amount of chromium which might be picked up in a Monel weld will be within the tolerable limits. Dilution by small amounts of nickel from the 18–8 plate is, of course, no problem. The important point is that the tolerance for chromium in a Monel composition is appreciably more than the tolerance for copper in a stainless steel composition. Even in the Monel weld, however, chromium can be troublesome if allowed to run too high. A safe limit would be something of the order of 6–8%.

The Monel to stainless type of joint was also successfully completed with nickel electrodes, which can be considered an alternate choice for this type of joint.

Strong ductile joints were prepared between Monel and nickel and between Monel and Inconel, in both cases, with either matching electrode. A Monel to cupro-nickel joint, prepared with the Monel electrode, likewise exhibited good properties.

A Monel to Hastelloy "B" joint made with the 130-X Monel electrode had good properties but the same joint made with a Hastelloy "B" electrode was brittle in the bend test and broke under tensile load at 87% of the theoretically possible joint strength.

No successful joints were completed between Monel and silicon bronze. There was a strong hot cracking tendency at the weld-bronze interface which it was not possible to overcome in these tests. Methods of welding other than metallic arc welding would perhaps be more successful.

JOINTS WITH NICKEL AS ONE MEMBER

The properties of joints with commercial wrought nickel as one member are shown in Table 2. The most frequently encountered of these, as in the case of the Monel, is probably the joint with mild steel. Spraragen and Rosenthal,[4] in a review of dissimilar metals welding, refer briefly to the welding of nickel to mild steel with a Monel electrode but this procedure is believed to have been practiced only infrequently if at all in recent

Table 2—Physical Properties of Dissimilar Metal Joints Involving Nickel

Joint composition	*Electrode*	*Tensile strength, psi.*	*Joint efficiency, %*	*—Bend test elongation, %—* *Longitudinal*	*Transverse*
Nickel to:					
Mild Steel	140 Monel	64,000	100	49	...
	131 Nickel	65,000	100	...	20
	132 Inconel	64,000	100	43	...
	19–9 Cb Stainless	63,000	100	34*	...
Type 304 Stainless	131 Nickel	65,000	100	30	...
	132 Inconel	66,000	100	...	25†
	133 80–20	66,000	100	43†	...
	19–9 Cb Stainless	65,000	100	48†	...
Type 321 Stainless	131 Nickel	65,000	100	38	...
	132 Inconel	66,000	100	43	...
	133 80–20	65,000	100	45	...
	19–9 Cb Stainless	65,000	100	51†	...
Type 316 Stainless	131 Nickel	66,000	100	22	...
	132 Inconel	65,000	100	46†	...
	133 80–20	65,000	100	42†	...
	18–12 Mo Stainless	65,000	100	48	...
Type 347 Stainless	131 Nickel	65,000	100	33	...
	132 Inconel	65,000	100	46	...
	133 80–20	66,000	100	46†	...
	19–9 Cb Stainless	66,000	100	47†	...
Inconel	131 Nickel	66,000	100	27	...
	131 Inconel	66,000	100	46†	...
	133 80–20	65,000	100	45†	...
70–30 Cupro-Nickel	130-X Monel	60,000	100	47†	...
	137 Cu-Ni	53,000	100	47†	...
Hastelloy "B"	131 Nickel	65,000	100	35	...
	132 Inconel	65,000	100	45†	...
	Hastelloy "B"	66,000	100	22	...
Silicon Bronze	131 Nickel	29,000	50	Nil‡	...

* Many fine cracks in weld.
† No failure at indicated elongation.
‡ Failed in hot-crack at weld-Si bronze interface.

years. The nickel electrode has been used for this type of joint, however, and in this series of tests shows adequate strength, with 20% elongation in transverse bend. Somewhat better ductility values and equally good strengths are shown by nickel to mild steel joints welded with either the new, low-carbon Monel electrode or the Inconel electrode. On the basis of ductility alone either of these latter two electrodes would be a better choice than the nickel electrode, but at 20% elongation and with no hot cracking tendencies there is probably sufficient margin of safety with the nickel electrode to justify its use for most applications.

The data for the nickel to mild steel joint welded with a columbium-stabilized 19–9 electrode show 100% joint efficiency and 34% elongation. However, the weld contained hot cracks, particularly in the top-layer bead next to the nickel plate. These cracks were very small, perhaps $^1/_{32}$ in. long or less, and failed to propagate further in the bend test until the indicated elongation was reached. These same cracks also opened up in the tensile specimens but their presence was not reflected in low physical properties, apparently because of the inherently high strength of the weld metal compared to the strength of the nickel. How important this slight hot cracking tendency might be from the practical standpoint is not certain but it is entirely possible that cracks such as these could lead to early failures with repeated applications of stress.

The reason for this hot cracking tendency is not wholly apparent but a plausible explanation can be derived if an entirely reasonable 20% dilution of the 19–9 composition by nickel is assumed. Such a dilution would result in a weld composition containing approximately 27% nickel and about 15% chromium. This composition can be recognized as approaching that of the commercial 35–15 alloy composition which is notoriously difficult to deposit free of hot cracks.[5] It is entirely possible that the 19–9 electrode, adequate though it may be for welding plate of the same composition, is not properly controlled with respect to the amounts of silicon, carbon, phosphorus, etc., to resist the hot cracking tendencies of the 35–15 composition.

Good properties were obtained on test joints between nickel and the several types of stainless steel welded with any of the following electrodes: nickel, Inconel 80–20 nickel-chromium and stainless steel. The low-carbon Monel electrode was not included in this series of tests but could be expected to perform almost as well in this type of a joint as it did in the mild steel to nickel joint. The stainless type of electrode performed better in welding stainless to nickel than it did in welding mild steel to nickel although the composition of the top layer bead next to the nickel should be approximately the same in one as in the other. It may be only a matter of variation in penetration, unwittingly made, but with sufficient effect on weld composition to account for the different results. In any event, avoidance of the sensitive 35–15 composition is perhaps best assured by using one of the high-nickel electrodes.

The Inconel electrode and the 80–20 nickel-chromium

Table 3—Physical Properties of Dissimilar Metal Joints Involving Inconel

Joint composition	*Electrode*	*Tensile strength, psi.*	*Joint efficiency, %*	*—Bend test elongation, %—* *Longitudinal*	*Transverse*
Inconel to:					
Mild Steel	132 Inconel	68,000	100	..	24*
	133 80–20	68,000	100	..	26*
	19–9 Cb Stainless	64,000	100	30†	..
Type 304 Stainless	132 Inconel	94,000	100	50	..
	133 80–20	95,000	100	53*	..
	19–9 Cb Stainless	86,000	92	54	..
Type 321 Stainless	132 Inconel	94,000	Nearly 100	53	..
	133 80–20	94,000	Nearly 100	50*	..
	19–9 Cb Stainless	87,000	About 90	42	..
Type 316 Stainless	132 Inconel	92,000	100	50*	..
	133 80–20	91,000	100	50*	..
	18–12 Mo Stainless	81,000	90	52*	..
Type 347 Stainless	132 Inconel	92,000	100	49*	..
	133 80–20	93,000	100	48	..
	19–9 Cb Stainless	84,000	91	44	..
70–30 Cupro-nickel	131 Nickel	59,000	100	34	..
	132 Inconel	58,000	100	39	..
Hastelloy "B"	132 Inconel	99,000	100	50	..
	Hastelloy "B"	99,000	100	28	..

* No failure at indicated elongation.
† Many fine cracks in weld.

electrode appeared to be the best choices for joining Inconel to nickel, with the nickel electrode an alternate choice but showing somewhat less room temperature ductility than the other two. Good joints were prepared between nickel and cupro-nickel with both the 130-X Monel electrode and the cupro-nickel electrode.

Good nickel to Hastelloy "B" joints were completed with both the nickel and the Inconel electrodes. The same joint made with Hastelloy "B" electrodes showed somewhat less ductility than the others, although at 22% elongation there was probably adequate ductility with this electrode for most applications. The nickel to silicon bronze joint, like the Monel to silicon bronze joint, failed by severe hot cracking at the junction line between the weld and the silicon bronze.

JOINTS WITH INCONEL AS ONE MEMBER

The properties of joints made between Inconel and other metals are shown in Table 3. In making the Inconel to mild steel joint with stainless electrodes the same mild hot cracking tendencies were noted that were noted in making the nickel to mild steel joint with the stainless electrodes. The explanation which was offered in the case of the nickel to mild steel joint would apply equally well in this case, since a weld composition approaching that of the sensitive 35–15 composition would result whether the 19–9 composition were diluted with nickel or Inconel. The Inconel and 80–20 nickel-chromium electrodes showed no such hot cracking tendencies and the physical properties were more than adequate.

Good properties were obtained in the Inconel to stainless series of joints with either the Inconel or the 80–20 nickel-chromium type of electrode. The same joints welded with the stainless type of electrode showed adequate ductility values, but joint efficiencies fell off, somewhat, to about 90%, and slight hot cracking tendencies were again evident. As before, the significance or seriousness of these hot cracking tendencies with a nickel-diluted 19–9 weld composition cannot be fully assessed but a potential hazard must be recognized.

Good test joints between Inconel and 70–30 cupro-nickel were obtained with either Inconel or nickel electrodes and between Inconel and Hastelloy "B" with either Inconel or Hastelloy "B" electrodes.

DISCUSSION

In interpreting the data of Tables 1, 2 and 3 it must be remembered that the properties shown are those of joints made under only one set of conditions—a downhand butt weld in $^3/_8$-in. thick plate with dilution by plate kept to a near minimum. While it is good practice, and one that should be strongly recommended in dissimilar metals welding, to keep dilution by plate at a minimum, it is inevitably true that other joint designs or other plate thickness, even under otherwise similar welding conditions, would have resulted in different amounts of dilution and consequently in different weld metal compositions. At least some of these would be expected to exhibit different physical properties.

Even with the simple butt weld in $^3/_8$-in. thick plate it is apparent that the two top beads cannot be alike in composition (Fig. 2). It is conceivable, even, that each of the other three beads contain greater or smaller amounts of remelted plate material than the others. To this extent each joint represents a range of compositions, but the dilution effects experienced in day to day fabrication welding can be expected to result in much wider composition ranges. Thus, the choice of electrode for completing a dissimilar metals joint seems to boil down to the selection of an electrode composition which, in spite of varying amounts of dilution, remains capable of meeting a required performance standard.

Table 4—Electrode Performance Ratings for Dissimilar Metals Welding

Joint	Electrode: Monel 130	Nickel 336	Inconel 132	80 Ni–20 Cr 133	Cupro-Nickel 137	Stainless	Ferritic	Hastelloy "B"
Monel to:								
Mild Steel	G	F†	G	G	..	P	P	..
Stainless	V	F†	G	G	..	P	P	..
Inconel	G	G	G	G	..	P	P	..
Nickel	G	G	G	G	..	P	P	..
Cupro-Nickel	G	G	..	..	G	..	..	..
Hastelloy "B"	G	G	..	..	..	..	..	P
Si Bronze	F	F	..	..	..	..	..	..
Nickel to:								
Mild Steel	V	F†	G	G	..	V	P	..
Stainless	..	F†	G	G	..	V	P	..
Inconel	..	G	G	G	..	V	P	..
Monel	G	G	G	G	..	P	P	..
Cupro-Nickel	G	G	..	..	G	..	P	..
Hastelloy "B"	..	G	G	..	..	..	..	F
Si Bronze	..	P	..	..	..	..	..	..
Inconel to:								
Mild Steel	..	F†	G	G	..	V	P	..
Stainless	..	F†	G	G	..	V	P	..
Monel	G	G	G	G	..	P	P	..
Nickel	..	G	G	G	..	V	P	..
Cupro-nickel	..	..	G	G	..	..	..	..
Hastelloy "B"	..	..	G	..	..	..	..	G

* V = Variable, G = Good, F = Fair, P = Poor.

† "F" rating assigned because of high weld hardness and somewhat lowered room temperature ductility, otherwise "G" rating would apply.

The test results referred to above serve to point out some of the obviously poor electrode choices and, at the same time, where the properties are more than ample, some of the choices which might be expected to perform well under a variety of welding conditions. In some cases, additional information has been gained from field experiences, by which it is possible to predict the probable effects of greater or smaller amounts of dilution. Where this was available it was discussed earlier in the text along with the presentation of the test results. Other combinations may require further test work to determine the effects of variable amounts of dilution.

The mass of information obtained is too complex to make possible many generalizations but the test results do seem to indicate, in general, that when a high-nickel alloy is metallic arc welded to another dissimilar metal, a good choice of electrode is the one which matches the composition of the high-nickel alloy involved. This trend probably reflects a singular property of the element nickel—its mutual solubility with a wide variety of other metals. Thus, if an electrode composition is selected which is initially high in nickel there is a greater probability of obtaining a single-phase plate-diluted composition than there is if the starting point is some other metal which dissolves dissimilar metals less readily. With a high-nickel base there is also no likelihood of a composition which undergoes a phase transformation on cooling.

In Table 4 are shown, in summary form, quality ratings for a large number of electrode and plate compositions. These ratings are based largely upon the results of the physical test data, but they also reflect some interpolated results and various experiences gained over a period of time, in the welding of high-nickel alloys. Ferritic electrodes, for instance, although not included in the test program, are known to be generally unsatisfactory where a high-nickel alloy is involved. By picking up as little as a few per cent of nickel with a ferritic electrode, a hardenable weld composition results which is almost certain to crack.

CONCLUSIONS

1. Physical properties have been determined for a group of some 70 or more dissimilar metal test joints, all containing a wrought high-nickel alloy as one member. With a few exceptions, the various plate-electrode combinations yielded joints having adequate strength and ductility under the test conditions employed.

2. Since conditions encountered in fabrication welding may vary considerably with respect to stress, joint design and plate dilution, each application should be examined carefully with these variables in mind.

3. Certain weld compositions should be avoided. These include the following:

(*a*) A ferritic weld deposit if dilution by nickel, chromium or copper is to be encountered.

(*b*) The 18–8 type of weld deposit if dilution by more than 3% of copper is to be encountered.

(*c*) A high-carbon Monel deposit if dilution by iron is to be encountered.

(*d*) Any Monel deposit if dilution by more than 6–8% of chromium is anticipated.

(*e*) The 18–8 type of deposit if dilution by nickel and chromium is sufficient to result in the crack-sensitive 35 Ni–15 Cr weld composition.

4. A guide to the selection of electrodes least sensitive to plate dilution problems is given in Table 4.

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Discussion by Hallock C. Campbell

This is a helpful paper in a field which until now has had few signposts. Particularly instructive is the authors' clear statement of the effect of carbon in Monel welds. When the first low-carbon Monel electrode was introduced in November 1945, the advantages of the low carbon content were occasionally obscured by the occurrence of porosity. With the elimination of this defect in the latter part of 1948, the advantages of a low carbon formulation became fully evident. Pease and Bott, through their work in developing a similar electrode and in surveying the field of dissimilar metal welding, have been able to recognize the physical and chemical principles governing this new electrode type.

I would like to add briefly to the comments made by Mr. Jessen. At first glance the authors appear to be unjust in reporting the performance of stainless steel electrodes in Table 4 as "variable." In Table 2, welding nickel to stainless steels, for example, all four tests with stainless electrodes showed better elongation than any of the other 12 tests made on nickel-to-stainless joints. I have since recognized, however, that the authors' arguments are based not only on the four tests reported but also on field experiences with dissimilar metal welds. Their surmise that joint compositions in the 15 Cr–35 Ni range may be subject to cracking in the absence of careful silicon, carbon, and phosphorus control seems to me very reasonable.

This does not necessarily mean that all stainless electrodes are to be avoided in making dissimilar metal joints. I agree with Mr. Jessen that there is some question whether the proper choice of stainless steel electrode was made for these dissimilar metal welds. It is a generally accepted principle in welding stainless steels that the electrode should be chosen to match the plate composition. The use of stabilized electrodes to weld 304 material is definitely to be discouraged. In the case of dissimilar welds, the choice of electrode should also be made with the subject of weld dilution in mind. Type 347 weld metal, when diluted with nickel from the high-nickel alloys tested in this series, will be fully austenitic; this composition is generally considered more crack-sensitive than the straight 18–8 type. In my opinion a straight 18–8 electrode should have been chosen for the tests in 304 plate, and I think the same 18–8 electrode would have been more promising for the tests in types 321 and 347. Mr. Jessen's suggestion of a 25–20 electrode is also worth considering, but dilution with high-nickel plate material will more quickly raise this composition to the 15–35 range; a high-carbon low-silicon 25–20 electrode such as Mr. Jessen used would be desirable. A type 29–9 electrode would appear to be a good choice, since the high ferrite content of this grade will withstand greater dilution before becoming fully austenitic, and since these electrodes normally are higher in carbon than the 18–8 grades.

The authors' tests of welds involving silicon-bronze are helpful as a warning of what electrode not to use, but their speculations regarding "methods of welding other than metallic arc welding" seem out of order, since no tests with silicon-bronze electrodes were attempted. I have not made such a test myself, but I see no reason to expect a silicon-bronze electrode to exhibit any such hot cracking as the authors observed using Monel and nickel electrodes.

Turning to another aspect of the work, I would like to ask the authors for information on the subject of weld soundness. I believe the authors' survey may have given them an unequalled opportunity to observe phenomena which the rest of us see only at intervals. Obviously they experienced no difficulty with general or gross weld porosity; but I wonder if there were any indications of *tendencies* toward porosity? This might have been evidenced by occasional start porosity which was chipped out and rewelded, or by root bead porosity which was perhaps not unexpected and therefore ignored. Perhaps the welder observed that certain plate-and-weld combinations required more care or manipulation than others. Porosity periodically rears its ugly head in production welding, no matter how foolproof the manufacturer thinks he has made the electrode. Is this not more likely to occur with high-nickel electrodes than with stainless electrodes, and thus on some dissimilar metal combinations make the stainless preferred? I believe the authors should be in a position to make a significant contribution to our knowledge if they will re-examine their present data with the subject of porosity specifically in mind.

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Magnaflux Inspection of Welded Storage Tanks

Procedure for getting the best results in magnaflux inspection of tank seams is indicated. Special attention is given to such matters as surface finishing, spacing of prods, thickness of material, amount of powder. The limitations of the method are indicated

by F. A. Upson

INTRODUCTION

FOR many years it has been generally recognized that all-welded construction offers major advantages over riveted construction for storage tanks of the types ordinarily used for bulk storage of petroleum products in large volume. A good welded tank, for example, does not leak and, consequently, presents a better appearance than a riveted tank and involves less maintenance expense, such as for painting, for example. Secondly, a good welded tank, being free from projections on the inside surface of the shell, is more suitable for use with a floating roof than is a riveted tank. Thirdly, a welded tank offers substantial cost advantages over a riveted tank, size for size. Fourthly, in at least some sections of the country, riveters appear to be a dying race. It should also be noted that the very nature of the riveting process presents a practical limitation upon the size of tanks which can be erected thereby, because of the increasing difficulty, as plate thicknesses go up, of obtaining suitable riveted joints. (A practical size limitation of course likewise exists for welded tanks, but this limit is substantially larger than for riveted construction.)

Notwithstanding these many advantages, a certain reluctance to accept all-welded tanks has persisted due largely to the difficulty of establishing the soundness of the main seams. Storage tanks are highly stressed structures; working stresses customarily used in them are about 50% higher than in Code pressure vessels. Whereas a riveted tank employs a type of joint that is readily susceptible to ordinary visual inspection and simple manual tests, the joints in a welded tank may contain dangerous hidden defects even though they be of excellent appearance. Furthermore, since welded tanks are often erected by welders on a "piecework" or "bonus rate" basis, and since no reasonable means exists whereby a tank can be subjected to an overload test, the need for suitable comprehensive (as distinct from spot-check) inspection coverage of the main welded seams is evident.

Of all the seams in a welded tank, the vertical shell seams are nominally the most critical because they must carry the full primary shell stress. The circumferential seams carry no primary load, and ordinarily it is not required that they even be full penetration welds; however, at their intersections with the vertical seams, it is desirable that they be sound in order to facilitate insuring that the ends of the vertical seams are acceptable. It is considered very important that nozzle and manway welds and reinforcing pad attachment welds, when they are located in highly stressed areas, be sound and they should accordingly receive preferred attention. It is our usual practice to have heavy manway assemblies (including the sheets to which they are attached) prefabricated and stress relieved before welding them into the tank shell. Roof seams and bottom seams are not ordinarily considered critical from a stress standpoint, but past history has indicated the need of establishing the soundness of at least the outside ends of the radial joints in the bottom sketch plates; secondary stresses presumably are largely responsible for the occasional cracks that have originated in these locations and then progressed up the shell. The inside and outside fillet welds attaching the bottom shell course to the sketch plates likewise should be sound in order for them satisfactorily to withstand what are probably the most serious secondary effects in the entire tank.

The usual inspection operation that has been employed on the vertical and circumferential seams of welded tanks is to spot-check them by trepanning plugs at arbitrary locations on the seams. Such a procedure is probably satisfactory for the circumferential seams but its adequacy as applied to vertical seams appears open to serious question; as ordinarily handled, it can

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Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

result in as few plugs as one for each hundred feet of vertical seam in any course. Clearly, this is only a very meager sort of spot-check. Based upon about two years' experience, it is believed that when the proper technique is used, the magnetic particle inspection process, better known as Magnaflux, is suitable for comprehensive inspection coverage of critical joints in all-welded storage tanks.

EQUIPMENT REQUIRED AND SURFACE PREPARATION NEEDED

Equipment that is required for Magnaflux inspection of tank welds includes a suitable power source, cables for carrying power to the part of the tank being inspected, heavy copper prods for making contact with the welded seams and Magnaflux powder of a color such that suitable contrast with the weld surface is obtained. Magnaflux powder is available in gray, red and black colors. In general, it has been found that the gray powder is the most satisfactory, whenever lighting conditions and the color of the background permit its use, because it seems to be less susceptible to changes in atmospheric humidity. In humid weather, the red and black powders appear to absorb moisture from the atmosphere to a certain extent, with the result that they show a tendency to agglomerate, making it somewhat more difficult to apply them.

Ordinary direct current has been used in the Magnaflux process for many years but its usefulness for the detection of subsurface defects is believed to be limited and perhaps unreliable due, apparently, to the fact that the constant magnetic field resulting therefrom reduces the mobility of the magnetic powder particles as they are applied to the surface of the material being checked. Ordinary alternating current is satisfactory for the detection of surface defects, but, presumably as a result of hysteresis effects, the alternating field does not permit the detection of subsurface discontinuities. Half-wave rectified current, which results in a pulsating field of constant direction, obviates the difficulties associated with straight alternating current and, at the same time, provides for increased powder mobility on the surface of the specimen, thus permitting greater sensitivity to subsurface defects.

The size of cable required depends, of course, upon the power source, length of leads required by the job, and the amperage which must be carried. Ordinarily, low voltage current of from 600 to 1000 amp. is necessary.

The most serious types of defects to be found in a welded seam are elongated in a direction parallel to the seam; accordingly, any surface irregularities similarly oriented will tend to mask, by simple mechanical entrapment of the powder, any Magnaflux indication of a defect. For this reason, the most difficult type of surface to handle with the Magnaflux technique is where stringer beads have been left in the as-welded condition. In such a case, it is usually necessary to grind the surface even when only looking for surface cracks. In the case of the vertical seams in welded tanks, however, stringer beads are not employed, and this difficulty is consequently not encountered.

The principle of the Magnaflux process involves the accumulation of magnetic powder, on the surface of the material being checked, in regions where a discontinuity within the material results in a magnetic field distortion such that the field sensibly emerges from the surface. Accordingly, an appreciable overlay reinforcement on a weld will seriously reduce the subsurface sensitivity of the process. If the surface is smooth and flush, without overlay, then field distortion resulting from a subsurface defect will result in field leakage through the surface above the discontinuity. If a significant overlay exists, however, the distorted field will tend to follow through the overlay itself instead of cutting the surface, with the result that the magnetic powder will not form a pattern on the surface.

On tank welds in the field, the overlay is ordinarily held to a minimum in order to reduce the total amount of welding required and thereby to speed up the job and reduce the total cost of field labor. Experience has shown that if the finished weld is essentially flush with the parent plates, and is reasonably smooth, then removal of slag, loose scale and dirt is all that is required by way of surface preparation; no sensible advantage is gained by further dressing of the weld surface in such a case. If, on the other hand, the finished weld is essentially other than flush with the parent plates, or is unduly rough, then dressing of the weld surface such as by grinding will be required.

GENERAL METHOD OF PROCEDURE

In Magnafluxing a tank weld, the magnetizing current is passed through the weld itself in successive overlapping steps between the copper prods which are held in contact with the weld with a spacing ordinarily of from 4 to 8 in. The actual spacing used depends upon available current, sensitivity desired, plate thickness and to some extent upon the type of surface encountered. It has been found that spacings in excess of 8 in. are ordinarily not useful but that spacings somewhat greater than 4 in. are usually necessary in order to maintain a reasonable rate of progress. Generally speaking, a reduced magnetizing amperage or an increased plate thickness will require a reduction in prod spacing. This is because the subsurface sensitivity of the process is a function of the magnetic field strength which in turn depends upon the current density. Increases in plate thickness, however, appear also to increase the minimum useful prod spacing irrespective of magnetizing current values. The reason for this probably is that an unduly close prod spacing promotes preferential concentration of the magnetizing current near to the weld surface, resulting in a reduction of field strength available for the detection of subsurface discontinuities.

On the basis of information available to date, it appears that limitations in subsurface sensitivity, to be discussed hereinafter, make it necessary to employ multipass Magnafluxing when plate thicknesses over about $^3/_8$ in. are involved. For example, on $^1/_2$-in. material, Magnafluxing of the finished weld from both sides is considered necessary. On 1-in. plate, Magnafluxing of the back-chip, of the back-weld when half completed, and on both sides of the finished weld may be required. The exact amount of such Magnafluxing to be performed depends upon the experience of the individual operators, and upon the sensitivity desired, thicknesses involved, magnetizing current available and other associated variables.

Although special powder blowers are available and are sometimes valuable, it has been found that when working on vertical surfaces such as tank shells, application of the powder between the prods is more readily accomplished by merely shaking it from a rubber bulb. On a vertical surface, the excess powder falls off comparatively readily and the additional bulk of the powder blower is not justified. This is of very real practical significance since much of the work must be done from scaffolds. The powder should be used rather sparingly, because excessive amounts tend to mask otherwise recognizable patterns, and the experienced operator will learn more about the extent of subsurface defects by observing the motion of the powder as it is applied to the surface than by examination of final patterns.

Needless to say, the effectiveness of Magnafluxing a tank or any other structure can be enhanced considerably by proper attention to design details; for example, full penetration welds should be used wherever possible in joints which are to be Magnafluxed. This means that lap-welded details and other fillet welds with unfused roots should be avoided. Where this is not practicable, such as in the case of circumferential fillet welds attaching reinforcing pads to the shell and in the case of the fillet welds attaching the lower shell course to the bottom sketch plates, it may be necessary to use alternating current for magnetization in order to avoid picking up the unfused roots of the welds. (When this is done, however, it should be recognized that subsurface sensitivity is almost 100% lost.) In the case of the horizontal seams where they intersect with the vertical seams, full penetration welding is considered desirable for a few inches on each side of each intersection so that Magnaflux (using half-wave rectified current) can be used to determine the soundness of the horizontal seams at these points. The outside ends of the radial seams joining the bottom sketch plates can ordinarily be Magnafluxed using half-wave rectified current. Other seams in the tank bottom do not require Magnafluxing, nor do the roof seams.

No particularly unusual prerequisites are necessary for the Magnaflux operator other than those required of any good inspector but, because the Magnaflux indications obtained from subsurface defects usually lack the sharp definition characteristic of those resulting from surface cracks, a certain amount of experience in subsurface applications is desirable. It is also desirable for the operator to have a general comprehension of the theory of the process in order that he may better appreciate its limitations.

It has been found that one Magnaflux operator and, when necessary, a helper can ordinarily keep up with four to eight welders on tank work (depending on local conditions) provided, of course, that the Magnaflux equipment is arranged for adequate mobility. In order to achieve maximum results with minimum expense, it is necessary for the Magnaflux operation to follow immediately after the welding. This makes it necessary for the Magnaflux operation to be very carefully fitted in with the tank erector's schedule of operations so as to avoid unnecessary delays in the field. This is doubly important where multipass Magnafluxing is necessary. Experience has indicated that careful planning and joint cooperation between the erection crew and the Magnafluxing crew will result in no serious interference adversely affecting construction progress.

LIMITATIONS

Magnaflux is in no sense a cure-all for weld inspection problems nor should it be used to the exclusion of any other inspection technique. Magnaflux is, however, a valuable tool which can be used with good effect if it is used intelligently and with careful regard for its limitations.

Magnaflux should not be expected to reveal ordinary porosity or isolated slag pockets. On the other hand, slag stringers, cracks, lack of fusion and poor penetration, which are all elongated in the direction of the welded seam, can be revealed, provided they do not lie too far below the surface. (Sometimes Magnaflux will readily locate serious cracks that even radiography cannot find.) In general, it appears that when working on material of thicknesses ordinarily encountered in tank shells (not essentially greater than 1 in. thickness), the subsurface sensitivity obtained by Magnafluxing the finished weld should not be assumed to exceed approximately $^1/_4$ in., or $^1/_2$ the plate thickness, whichever is less, in material over about $^1/_2$ in. in total thickness. For material $^1/_2$ in. and under in thickness, these proportions can be modified as is inferred in a preceding paragraph.

Since the Magnaflux pattern resulting from a comparatively deep subsurface crack is more or less the same as might result from a slag stringer, for example, located closer to the surface, it is often difficult to determine the type of defect causing any particular indication. Accordingly, it is assumed that all Magnaflux indications require chipping. This is not an unreasonable basis on which to proceed because of the fact that the Magnaflux process is such that it ordinarily does not reveal inconsequential defects.

When Magnafluxing the back-chipped root of a weld, it will be found that the subsurface sensitivity is markedly reduced, presumably as a result of the shape of the bevel which extends upward from the root on each side

thereof. Accordingly, care must be used in settling upon a detailed method of procedure in any particular case so as to insure that the range of sensitivity realized in each pass is such as to overlap those of other passes. It should also be noted that sharp irregularities in the contour of the back-chipped groove may cause otherwise recognizable powder patterns to be masked; therefore, the choice of tools used for back-chipping is important.

Experimental work carried out on test plates having defects deliberately included therein must be done very carefully in order for any correlation with actual field conditions to be obtained. The most common pitfall in this regard appears to be that of welding over unfused lips, at the root of the weld, that have been placed in intimate contact with each other. The result of such a condition is to minimize the magnetic field distortion obtained because of the extremely narrow width of the defect. In actual tank erection work, of course, such a defect could not be realized because of the general practice of providing shims to space the plates a definite distance apart. Furthermore, should a situation such as this occur in the field, the time to discover it is before any backwelding has commenced rather than after all welding has been completed.

It should be emphasized again here that Magnaflux is not a substitute for other forms of inspection but rather that it should be used in conjunction with other forms in order to provide additional assurance of sound welds.

SUMMARY

It is necessary, in planning for a Magnafluxed tank erection job, that the operation be carefully fitted in with the erector's field schedule in order to avoid field delays. Furthermore, it is necessary that the tank erector be acquainted with requirements as to weld finish so as to eliminate the need for dressing of the seams. Half-wave rectified current should be used for magnetization except in those locations where the presence of an unfused root, such as on fillet welds, makes it necessary to use alternating current. Magnetizing currents of less than 600 amp. should not be employed and larger currents up to about 1000 amp. are ordinarily desirable.

In order to avoid disappointment in the Magnaflux process, it is necessary that its limitations be constantly borne in mind. In particular, situations affecting its subsurface sensitivity must be clearly and promptly recognized as they are encountered. A comprehensive understanding of the physical principles upon which it is based will best serve to accomplish these ends.

The Magnaflux process, if intelligently and carefully used together with other inspection procedures (including careful qualification of welders; visual inspection of fit-ups, back-chipping, inter-pass cleaning, and weld finish; and spot-check trepanning), should result in the elimination of dangerous weld defects from all-welded tanks.

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(*Continued on page 50*)

Inert-Gas-Shielded Arc-Welding Aluminum Pressure Vessels

Inert-gas-shielded arc-welding process, under proper procedure control, can assure welds of excellent quality and appearance on complex weldments and vessels of aluminum

by A. J. Hopper

INTRODUCTION

THE inert-gas-shielded arc process provides the fabricator with a tool which permits high class or code welds on wrought aluminum of heavy thickness. Welding speeds are good, no interpass or even final cleaning of welds is usually required, no flux is needed with its removal problem, the welds can be made in most positions and are sound with a good appearance. Mechanical properties of the completed welds can nearly attain the values of the parent aluminum. For high-quality fabrication of a few-of-a-kind types of aluminum vessels, this process is essential to meet the demands of the designers.

CONDITIONS

In discussing the practical problems that have been met in using the inert-gas-shielded arc process, certain conditions have been standard with our Company in nearly all cases. We have generally used 3S aluminum plate with occasional use of 2S and 61S. Stresses in welds have been figured in accordance with the annealed values of these materials. The 43S filler rod has been generally used because of its lower melting point and freedom from weld cracking, although it does have a lower ductility than the parent metal. The inert-gas-shielded arc process used consisted of a virtually non-consumable tungsten electrode in a water-cooled torch head that also emits an inert gas, argon, to completely shield the arc, electrode and weld metal. The sizes of tungsten electrodes and filler rods were varied to suit plate thickness and current used. Tungsten electrode diameters used were $^3/_{16}$, $^1/_4$ and $^5/_{16}$ in.; aluminum filler rods were $^1/_8$, $^3/_{16}$, $^1/_4$ and $^5/_{16}$ in. Current used throughout was a. c. with superimposed high frequency for arc stabilization.

LAYOUT AND ASSEMBLY

As most aluminum plate is shipped from the mills wrapped and crated, storage and handling of aluminum in the fabrication plant should be treated with the same respect. Aluminum is relatively soft, only one-quarter the hardness of steel. The normal run of steel tools found in the shop will mar the surface of aluminum plate. If possible, aluminum should be handled by tools just for aluminum and, furthermore, separate assembly areas should be provided for its fabrication. Rolls, shears and press brakes can, of course, handle both steel and aluminum, provided this equipment is cleaned and covered with heavy paper before working aluminum.

Clean welding grooves and clean filler rod are essentials to the inert-gas-shielded arc process on aluminum.

Partial assembly of aluminum heat exchanger

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Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

Grooves that are chipped just before welding are in proper condition. Where groove preparation must be made well beforehand, wire brushing just before welding and/or covering the grooves with masking tape proved invaluable.

Good fit-up of joints is desired in pressure vessel fabrication. Accurate layout must precede good fit-up in assembly. Aluminum will shrink about twice the amount of ordinary steel in the welding operation. Shrinkage allowance for welding should be made in layout, particularly if there are many welded seams and over-all tolerances to be met. Where any doubt exists that shrinkage during welding may cause partial collapse or flatness of shells at nozzle locations, this trouble should be avoided by the use of shell formers as hold-down jigs during welding. The number of tack welds should be generous to prevent troublesome distortion of plates when welded. Tacks should be chipped out and not welded over, to insure that the first pass penetrates evenly to the bottom of the groove.

WELD GROOVE PREPARATION

The preparation of weld grooves for butt joints in aluminum follows similar work in carbon steel with added refinements. The tungsten electrode will project $^{3}/_{16}$ to $^{5}/_{16}$ in. beyond the cup of the torch for normal gas shielding. In deep grooves, sufficient width must be provided in order to permit free manipulation of the torch head in the bottom of the groove. Butt weld types (*a*) through (*g*) are illustrated on Figs. 1 and 2.

Type (*a*). Note that a $^{1}/_{4}$ in. minimum thickness back-up strip is specified to insure root fusion without the ever-present danger of burning through.

Type (*b*). Where a back-up strip cannot remain, a grooved strip of heavier thickness may be used. This strip is chipped out after welding and the excess reinforcing provided by the groove is ground and blended to the parent metal.

Type (*c*). For longitudinal seams of small vessels or pipes of aluminum, a welding jig was used which, by air pressure in a flexible hose, forced a copper back-up bar against the bottom of the weld groove. The copper back-up bar was grooved $^{1}/_{4}$ in. wide by $^{3}/_{32}$ in. deep. Manual welding with the inert-gas-shielded arc process sometimes left two parallel oxide lines along the inside reinforcement. The original root edges had dropped down during the welding process. To eliminate these lines, the torch head without filler rod was played upon this inside reinforcement.

Type (*d*). Square edge butts, welded from both sides, would X-ray satisfactorily in thicknesses of $^{3}/_{16}$ and $^{1}/_{4}$ in.

Type (*e*). Square edge preparation with the far side chipped with a diamond point chisel would make satisfactory butt welds in thicknesses of $^{5}/_{16}$ and $^{3}/_{8}$ in.

Type (*f*). For plate thicknesses from $^{7}/_{16}$ up to $^{5}/_{8}$ in., a bevel preparation with 70° included angle and approximately $^{1}/_{8}$-in. land was used.

Type (*g*). With plate thicknesses from $^{3}/_{4}$ up to 2 in. either a single-U or double-U groove was used.

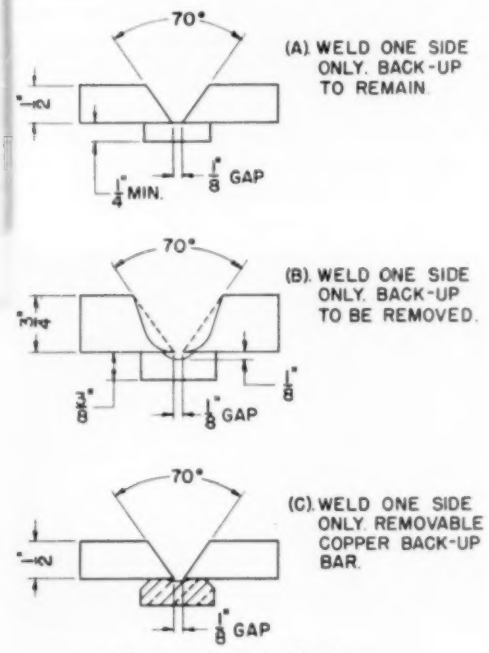


Fig. 1 Butt welds—aluminum

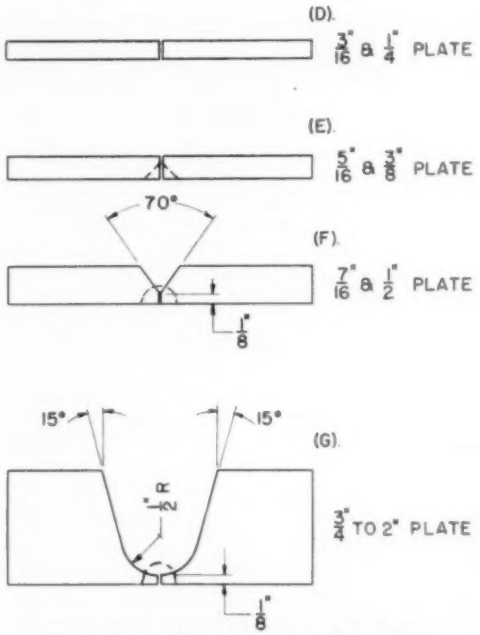


Fig. 2 Butt welds—aluminum weld both sides

Nozzle Connections to Shell

In making nozzle connections to shell, either the run or the branch (whichever permits access by the welding torch) is outside beveled 45° with $^1/_{16}$-in. land by chipping. (See Fig. 3). Excess aluminum $^1/_{16}$ to $^1/_8$ in. long is to remain on the run or branch not beveled. Welding first fills the beveled groove and the reinforcing fillet from the outside. The welding torch is then played upon the inside. No filler rod is required due to excess aluminum allowed. Sufficient current must be used in welding to break down aluminum oxide at the root of the bevel. This operation is probably the most important regarding the welding technique. Considerable skill is required in order to have the arc penetrate to the root. Excess material is then ground off.

Fabricated Stub Ends

Most nozzle connections to vessels were made with lapped joint flanges. Aluminum stub ends for use with these forged steel flanges can be purchased in many IPS sizes. However, our specifications called for the lap to extend out to the O.D. of the flange for the use with full face gaskets. These stub ends were fabricated from aluminum rings and sections of pipe. To suit the welding process, the pipe and rings were prepared for welding according to the diagram (see Fig. 4). It will be noted that welding on the first side is directed at the heavier plate, the lap ring. The second side was welded without back chipping. Here, care must be exercised in order to insure fusion at the root. (A 100% fusion or X-ray weld could only be guaranteed by back chipping.) Skilled welders, however, could insure 100% fusion without back chipping if the joints had been kept clean throughout the welding operation, and if the joints were

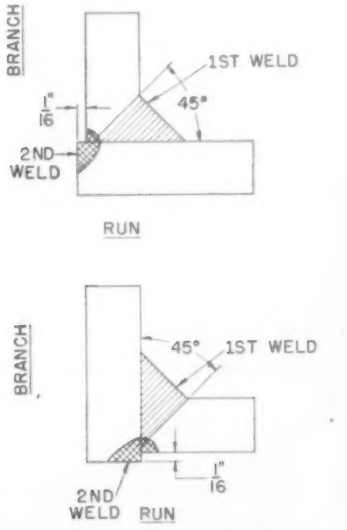


Fig. 3 Nozzle connections to shells

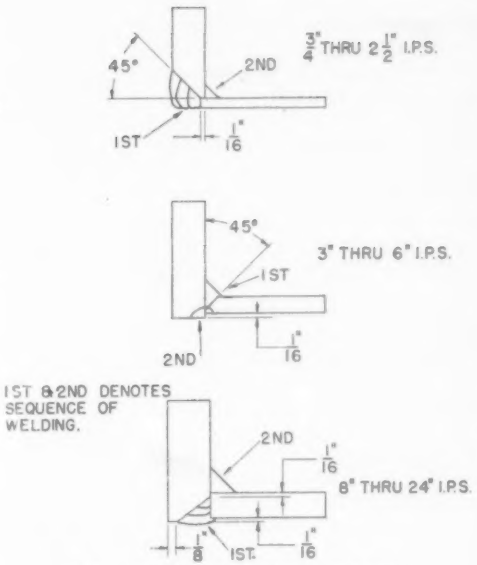
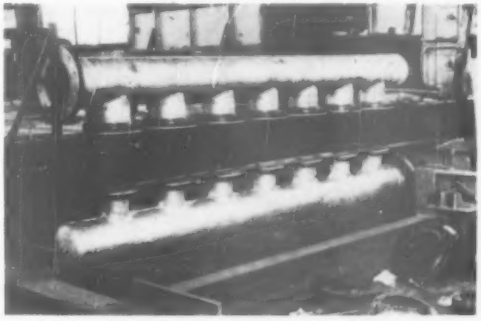


Fig. 4 Fabricated aluminum stub ends

welded continuously; i.e., the far side or seal pass was welded not too long after the original groove had been filled, or before the aluminum had become dirty. After all welding, these stub ends were machined all over on the lap to bring its thickness equal to that of pipe wall.

PREHEATING

On aluminum plate thicknesses of $^3/_{16}$ through $^7/_{16}$ in., no preheating is usually specified. From $^1/_2$ through $^3/_4$ in., preheating between 200 and 300° F. is usually done and at least 300° F. on thicknesses between 1 and 2 in. The heat conductivity of aluminum is about five times that of steel, so it is not unusual to find parent metal temperatures up to 500° F. after running the first pass with an initial preheat of 300° F. Preheating with strip heaters proved satisfactory when the entire subassembly could be raised in temperature and



Aluminum heaters on assembly and welding jig

insulated from the outside air. When individual joints on a main assembly required preheat, the temperature rise of the aluminum dissipated so rapidly that the groove temperatures did not reach 200 or 300° F. Sufficient heat could not be concentrated with the strip heaters. Propane torches were used in these cases, but the uneven heat caused a little more trouble with tungsten inclusions.

SPECIAL APPLICATION—WELDING TUBE SHEETS TO BARRELS

The heaviest welds made were those attaching $2^1/_2$-in. thick tube sheets to sections of shell 2 in. thick. Two shell sections were 62 in. I.D. by about 24-in. long rolled cylinders of 2 in. thick 38 plate and butt welded. The tube sheets were $2^1/_2$ in. thick 38 plate machined to an O.D. of 62 in. with a J groove $1^1/_4$ in. deep by $1^1/_2$ in. wide at the top. (See Fig. 5.) Assembly of these tube sheets in the barrels was done by heating the barrel to 300° F. and packing dry ice on the tube sheets—the tube sheets were pressed into place. Tacks were made on the side opposite the J groove. In order to assure flatness of the tube sheets, a hold-down jig was used during all welding operations. This jig held the tube sheet flat by exerting pressure from above and below. The barrel was restrained at the top and bottom by setting in a machined groove. Preheating and temperature control during welding was accomplished with 27 kw. of strip heaters below the tube sheet, and 15 kw. of heaters around the barrel opposite the weld joint. Switches were provided so that banks of heaters could be cut out. The barrel assembly was surrounded with magnesia blocks, the top of the tube sheet was also covered with these blocks leaving just sufficient

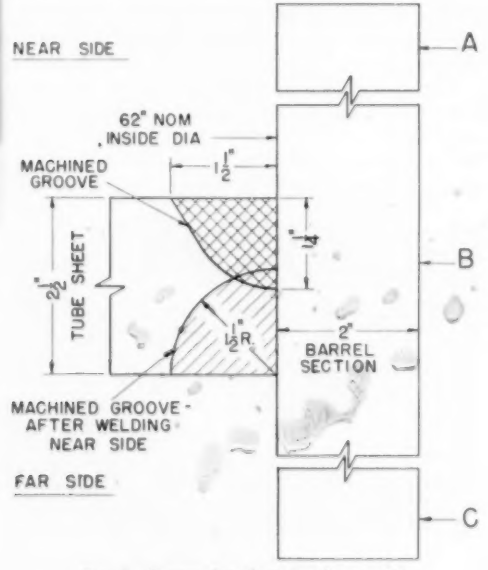
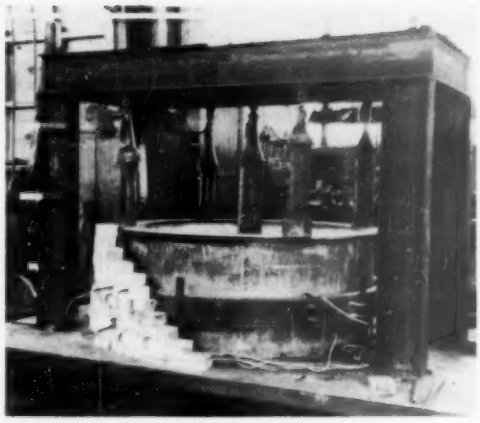


Fig. 5 Groove detail—tube sheet weld



Welding jig used in the special application of welding tube sheets to barrels

room at the weld groove. Preheating to 700° F. was accomplished in 4 hr. prior to welding. The temperature of the aluminum was held close to 700° F. throughout the welding. Temperature was checked with indicating crayons and varied by cutting out heaters as the welding heat was applied. Welding once started was continued until the groove was filled. Due to the intense heat, two welders worked alternate 15-minute shifts. Welding continuously, except time out for fatigue and adjustments to the welding torch, the J groove on the first or near side required about 24 elapsed hours. The assembly was allowed to cool slowly in the jig, requiring 10 hr. to reach 100° F.

At room temperature, check dimensions indicated that the barrel had shrunk about $^1/_8$ in. on circumference at the tube sheet, Location B. At Location A and C, shrinkage varied between $^1/_{16}$ and $^1/_8$ in. on circumference. The tube sheet remained flat.

X-rays were taken at eight points at random on the circumference of this weld before any work was done on the far side of the tube sheet. There were no cutouts. The X-rays indicated sound welds with little or no porosity, but with small amounts of tungsten inclusions. In a weld of this thickness, it was agreed to accept tungsten inclusions no bigger than $^3/_{16}$ in. diameter well separated, or groups of smaller inclusions as long as they were not touching or continuous.

The opposite or far side of the tube sheet was prepared for welding by machining a J groove with a radius of $1^1/_2$ in. and deep enough to penetrate the first passes from the original or near side. Barrel and tube sheet were again set in the welding jig with the $1^1/_2$ in. J up. After heating the aluminum to 700° F., welding was continuous to fill the groove in about 29 elapsed hours. After the long cooling-off period, the barrel and tube sheet were removed from the jig and checked dimensionally.

Total shrinkage of the barrel was the greatest at the tube sheet, Location B, measuring $^5/_{16}$ in. in circumference. The check dimensions in the top and bottom

of the barrel showed total shrinkage varying from $^1/_{16}$ to $^1/_4$ in. on circumference. The tube sheets were flat within $^1/_{16}$ in. X-ray films taken at random after all welding indicated no cutouts.

CONCLUSIONS

Comment on the rates of welding obtainable with the inert-gas-shielded arc process on aluminum has been purposely omitted until this paragraph, in order that the reader might obtain a clear picture of this particular application of the process. It can be seen that welding rates would reflect choice of grooves, quality of the weld metal, operator fatigue and, similar to any new tool, the elimination of operating and maintenance "bugs." For example, the special application of welding thick tube sheets to barrels averaged 1 lb. of aluminum rod per elapsed hour. On the other hand, a longitudinal butt weld 10 ft. long in a $^7/_{16}$-in. thick shell welded on a jig averaged 2 lb. of aluminum rod per elapsed hour. Stub end loss was low, spatter loss was nil and there was no flux loss. Argon consumption was relatively high, between 40 and 50 cu. ft. per hour on the tube sheet weld where conditions were extremely hot for the operator and equipment, and where weld quality and control of distortion were of prime importance. Other aluminum welds required between 15 and 30 cu. ft. of argon per hour, depending upon the amount of preheat, design and accessibility of the weld. The consumption of the tungsten electrode ran about 1 in. for 25 lb. of aluminum filler rod used.

Fifteen years ago, aluminum weldments had to be simple in order to control distortion during the welding operation with processes then used. Weld appearance and quality left much to be desired. Today, the inert-gas-shielded arc process can assure welds of excellent quality and appearance on complex weldments and vessels of aluminum.

Shielded Stud Welding of Aluminum Alloys

by Edward Dash

INTRODUCTION

NOWHERE in the literature has there appeared any information relative to the stud welding of aluminum alloys and nowhere, to the author's knowledge, has a suitable process been used, other than shielded stud welding,* by which the end welding of aluminum studs to aluminum alloys could be successfully accomplished. It is the purpose of this paper to give a short history of the development of this process and to give some details of the equipment used and some of its possible applications.

At the beginning of the last war, many engineers became aware of the problem of securing fibrous glass board insulation to aluminum alloy bulkheads on Naval warships in order to withstand gun shock and impact. Because of the consistently poor welds obtained at that time by attempting to use aluminum stud welding, and also because glue or cement used alone provided unsatisfactory adhesion, an alternate procedure was adopted of riveting steel pads to the aluminum bulkheads and stud welding steel insulation studs to these pads. It is obvious that such a procedure was time-consuming, added weight where weight was specifically designed to be minimized and was extremely costly.

In a series of experiments the author proved to himself that satisfactory aluminum end welds on AL61ST could be accomplished in an atmosphere of inert gas. These welds successfully met the requirements of a hammer bend test, were characterized by good physical properties with macro-etched specimens indicating freedom from cracks, porosity and inclusions and showing adequate penetration and fusion to the parent metal.

The method of inert-gas-shielded stud welding, submitted to the Navy and tested in a series of comprehensive tests under the cognizance of the Welding and Casting Section of the Bureau of Ships, is now an established process being used at various naval activities, and is listed in the standard "Master Chart of Welding Processes" published by the AMERICAN WELDING SOCIETY.

EQUIPMENT

The equipment necessary for the process comprises the following:

(*a*) A source of reversed polarity, direct current.
(*b*) An automatic stud welding gun with an inert gas adaptor.
(*c*) An automatic timer.
(*d*) Cylinders of inert gas.

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The statements and opinions expressed in this paper are those of the author and do not necessarily represent those of the Navy Dept.

* Patent pending by author

(*e*) A regulator and gas flow meter.
(*f*) A solenoid valve.
(*g*) A supply of aluminum welding studs.

Describing the components of this equipment in greater detail and in the order shown above:

(*a*) The source of d.-c., reversed polarity may be obtained either from a single-operator, variable-voltage motor-generator set or from a multi-operator, constant-potential motor-generator set used in conjunction with a resistance control panel for current adjustment. Current requirements will vary depending upon the diameter at the welding end of the stud. (A single operator set of 400 amp. capacity can be used for straight conically pointed studs up to and including $^{5}/_{16}$ in. in diameter.)

(*b*) Any automatic-type stud welding gun, fitted with a suitable adaptor at its end to provide the inert atmosphere for the stud weld, is satisfactory. Porcelain ferrules have not been found necessary in obtaining sound welds with studs up to and including $^{5}/_{16}$ in. in diameter.

(*c*) Although timers of the mechanical type are satisfactory for steel stud welding, it is considered that the more accurate timer of the electronic type is more desirable primarily because the characteristic of narrow plastic ranges of aluminum alloys necessitates accurate timing. This is especially true when welding thin-gage aluminum where a large error in the timing would cause the stud to pierce the thin material because of excessive heat.

A commercially available electronic sequence timer ordinarily used with resistance-welding equipment and incorporating at least three time delay relay circuits may be used satisfactorily with the shielded-aluminum stud-welding process. The definition of the "squeeze time" is converted in the latter process to mean that time during which the inert gas flows prior to the initiation of the welding current and the arc. The definition of the "weld time" remains the same, i.e., measuring out the time for the welding current. The definition of the "hold time" is converted in the stud-welding process to that time during which the inert gas continues to flow after the welding current has stopped.

(*d*) Experimental work performed to date indicates that double charcoal purified, welding-grade helium is preferable to argon in the shielded-aluminum stud-welding process, because welds of good quality appear to be more consistent in an atmosphere of helium. This may be attributable to better shielding of the arc obtained with the relatively lighter helium in positioned welding particularly in the overhead position.

(*e*) An ordinary oxygen regulator and flow meter of the type usually employed in inert-gas-shielded arc welding is also used in this process.

(*f*) A 110-v., a.-c. solenoid valve is connected into the gas line between the flow meter and the gas adaptor on the stud welding gun.

(*g*) Aluminum welding studs successfully used in this process are manufactured from aluminum alloy containing approximately 5% silicon and known in the trade as Al-43. As is well known, this alloy has found wide application in the fusion welding field and now in the shielded-aluminum stud-welding process because of freedom from hot-shortness and cracking in the weld metal deposit.

It has been the author's experience that the shape of the welding end of the stud is not critical, excellent results being obtained with straight conically shaped studs containing an angle of approximately 135°. No arc-initiating material is necessary.

APPLICATIONS

As indicated in the introduction, this process is now being applied by the Navy for securing fibrous glass board insulation to 61S aluminum bulkheads. This method consists essentially of end welding threaded studs to the bulkhead at approximate 18-in. centers, impaling the fibrous glass board over the studs, installing a washer over and then fitting a nut on the stud. Such bulkheads vary in thickness from $^{1}/_{16}$ to $^{1}/_{4}$ in.

The author has also performed some experimental work, which is not yet completed, on 24ST aluminum alloy. Results to date indicate that sound welds may be obtained without cracking in the base material and that such welds can consistently withstand a hammer bend test without failure. Experimental work is now being done on thin gage Alclad 24ST aluminum. Schedules for different thicknesses of various aluminum alloys which will include data on current, arc voltage, gas flow, stud size, etc., are also being prepared and will be submitted as a later report.

However, enough work with the process has been accomplished to indicate that shielded aluminum stud welding should find wide application in the fabrication of aluminum products.

ACKNOWLEDGMENTS

The author wishes to express his indebtedness to the welding shop personnel and management of the Long Beach Naval Shipyard for their cooperation in the conducting of tests and to the Welding and Castings Section of the Bureau of Ships for its vision in developing and applying the process of shielded aluminum stud welding.

Arc Welding of Molybdenum

Data are presented on the submerged arc welding of molybdenum in the production of sound welds. Inert-gas-shielded arc and atomic hydrogen may be also used for sheets less than 1/4 in.

by I. S. Goodman

Abstract

As the technique of producing pure molybdenum in a greater variety of shapes and sizes has improved, and as the requirements for high-temperature alloys may increase, a corresponding demand has appeared for better methods of joining molybdenum.

Thin sections may be resistance welded or brazed with ease but, for heavier sections, the resistance-welding power demand is too high to be practical and brazed joints do not possess temperature and/or corrosion resistances for many applications. Arc welding appears to be the only nonmechanical method for joining large or thick molybdenum sections so that the joint has comparable properties to the base metal.

Data are presented and discussed with accompanying microphotographs which indicate that submerged arc (or melt) welding offers the best potentialities for sound joints. Inert-gas-shielded arc welding and atomic hydrogen welding are discussed briefly since present techniques limit their use to sections less than 1/4 in. thick. Manual arc welding does not appear feasible.

INTRODUCTION

DURING the past several years, techniques have been developed for producing molybdenum in a large variety of shapes and sizes. Pressed and sintered ingots averaging 24 kilos have been rolled to slabs 1/2 x 14 x 17 in. (two slabs per ingot) and these slabs have been further rolled to 0.020 x 24 x 60-in. sheets, several times larger than any available heretofore. Improved stamping and spinning techniques have produced one-piece molybdenum containers ranging from 1–10 in. I.D. and from 1/2–4 in. deep from sheet stock 0.020 to 0.060 in. thick as well as smaller sizes from lighter stock.

Normally, molybdenum enjoys a preferred position among the refractory metals due to its lower cost. This demand has been accelerated by the current search by physicists and metallurgists for high-temperature metals and alloys for aeronautical and atomic research.

On its credit side, molybdenum has a high melting point (2620° C.), a high electrical and thermal conductivity, good ductility in the worked condition and desirable corrosion resistance to many chemical reagents. On its debit side, molybdenum oxidizes readily above 400° C. in the presence of oxygen, the oxide (MO_3) being volatile though not toxic. Also the large coarse recrystallized grain structure typical of overheated molybdenum is quite brittle. (Molybdenum will start to recrystallize above 900° C., but such heating for short times may be beneficial rather than detrimental to the tensile properties; as with other metals the eventual recrystallized grain structure will be a function of time, temperature and the previous history of the material.)

Considering these two faults, it will be appreciated that arc welding, which exposes the base material to air at oxidizing temperatures and whose time-temperature product results in large coarse grains, should be the least desirable method of joining molybdenum. That it is.

Of the common methods, other than arc welding, of joining metals we may mention mechanical bonding (e.g., rivets, lock-seams, etc.), brazing and resistance welding. It is hoped to discuss these other methods more precisely in future papers, but we may consider them briefly here and emphasize the fact that, contrary to the published experiences of other sources, we have not found the bonding of molybdenum difficult by these methods.

Mechanical bonding is an inexpensive and straightforward method, particularly on lighter sections, but is not applicable to many designs and is generally unsatisfactory for liquid-tight or gas-tight applications.

Brazed joints can be made with a wide variety of brazing alloys ranging from the common silver-brazing alloys at the lower end of the temperature scale to platinum and palladium and molybdenum alloys at the upper end. Brazing-alloy application and heating methods are the same as those in brazing conventional metals except that brazing must be carried out in hydrogen, nitrogen or one of the inert gases. It is also helpful to utilize brazing alloys containing small quantities of nickel or other elements alloying with moly; for copper, zinc and silver alloys a nickel plate on the moly will give better adhesion and strength.

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Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

Cupro-nickel alloys are cheap and give excellent joints with a choice of temperature range. One common brazing application involves molybdenum resistance electrode tips. However, many applications for molybdenum require the corrosion resistance and temperature protection of the original molybdenum metal which are not shared by the brazed joints.

With the advent of precise short period resistance welding timers and welder heads with fast follow-up, great strides have been made during the past several years in resistance welding of molybdenum. Difficulties have been the high conductivity and high melting point of the metal and the weakness of the joint in the weld-nugget boundary (due to unrelieved stress between the recrystallized nugget and surrounding as worked base metal and oxide inclusions). Nevertheless, we are fabricating an increasingly large percentage of previously mechanically bonded joints with resistance welding, the most recent being several cylinders 6 in. I.D., 6 in. high, of 0.020- to 0.060-in. stock which were resistance seam spot welded gas tight. However, due to its high conductivity and high melting point, so much kva. is required for successively heavier stock as to make resistance welding inadvisable on sheet material over 0.100 in. thick.

It will thus be seen that applications exist or may arise for molybdenum assemblies that require a high corrosion resistance and high-temperature operation so as to exclude brazing, of $\frac{1}{8}$ in. or thicker stock so as to exclude resistance welding, requiring gas or liquid tightness so as to exclude mechanical bonding and of sufficient complexity to make forging, stamping or spinning improbable. It is for such applications that we turn to arc welding with a full realization of the limitations of the resultant metallurgical structure.

For several years the Welding Section of the Westinghouse Research Laboratories at East Pittsburgh under J. Heuschkel and we at the Lamp Division have collaborated in experiments on inert-arc welding of molybdenum. More recently a concentrated program on submerged-arc welding of molybdenum was carried out by the Lamp Division of the Westinghouse Corp., under the writer's supervision using the facilities of the M. W. Kellogg Corp. at Jersey City. In this phase of the study, we would like to acknowledge the valuable assistance of W. Bunn and J. Schenk of the Kellogg Corp. The remainder of this paper presents the data arising from these studies and a discussion thereof. We trust it will stimulate further investigations on this subject since we fully appreciate that our work to date has been primarily of an exploratory nature.

THE SUBMERGED ARC-WELDING PROCESS

It is assumed that most of the readers of this paper are familiar with the submerged-arc-welding process but, for those who are not, a short description follows for which full credit is due the A.W.S. *Welding Handbook*.

Very early in the progress of electric arc welding, a need was recognized for some form of protection for the weld metal from the atmosphere. The first developed methods were coatings applied to the consumable

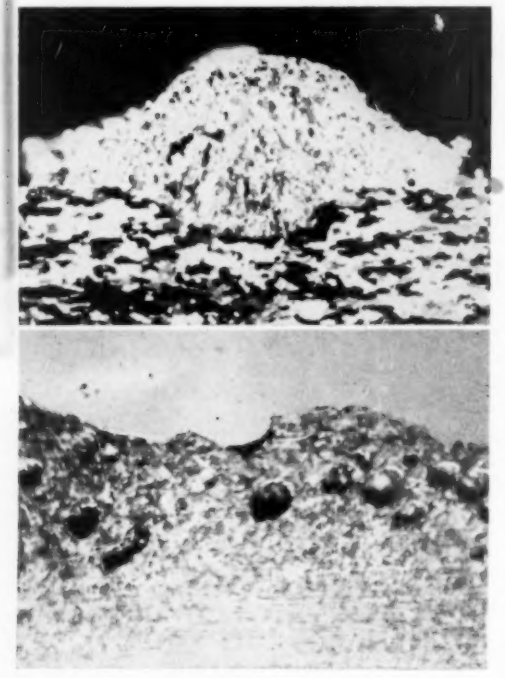

Fig. 1 Test 7 (7 ×)
Fig. 2 Test 82 (7 ×)

Fig. 3 Test 7 (200 ×)

electrodes of hand welding. After this came various attempts to introduce mechanization to the welding process by reducing its dependence on the welding operator. The first powdered fluxes that were developed for separate introduction into the weld zone, while a base electrode material was continuously and mechanically fed, frequently produced a very vigorous arc action with sparking and sputtering of metal and was known as smothered arc welding. It did not obtain very wide attention.

But gradually more satisfactory fluxes and techniques were developed so that there was no visible evidence of the arc during the welding process and this, now widely accepted process, is known as submerged arc or submerged melt welding.

In this process, the consumable welding electrode is not in contact with the work, but the current is carried across the gap through a flux. This flux is a completely reacted, specially manufactured granulated material which is nonconductive when cold but a highly resistant conductive medium when molten. It is applied over the weld area. The initial passage of current between the welding rod and base metal is accomplished by placing a small ball of steel wool between them.

SUBMERGED ARC WELDING VARIABLES ENCOUNTERED IN MOLY WELDING

Bead vs. Weld

All of the initial tests and most of all the total tests made were concerned with the laying down of beads or passes on single flat plates rather than the making of welds. This was done in order to conserve material, and to avoid the additional variables present in a weld which would not enter into the development of any initial technique. The final tests, as indicated on Table 1 were actual butt, tie and lap joints between two pieces of material.

Table 1—Submerged Arc Test Data*

Test No.	Bead or weld	Flux	Welding rod material	Thickness base metal	Current, amp.	Voltage, v.	Rate of travel, in./min.	Preheat, ° F.	Surface appearance, remarks
58	B	Mix 15	1/8-in. moly	7/16-in. moly	350	35	10	500	Stable arc, good bead
59	B	Mix 12	1/8-in. moly	7/16-in. moly	400	30	10	600	Stable arc, good bead
60	B	Mix 22	1/8-in. moly	7/16-in. moly	400	30	10	600	Stable arc, good bead
61	B	Mix 21	1/8-in. moly	7/16-in. moly	375	31	10	600	Stable arc, good bead
62	B	Mix 29	1/8-in. moly	7/16-in. moly	400	30	10	600	Stable arc, good bead
63	B	Sp. stainless flux	1/8-in. moly	7/16-in. moly	375	31	10	1000	Poor
64	B	Mix 30	1/8-in. moly	7/16-in. moly	400	30	10	600	Slag inclusions
65	B	Mix 31	1/8-in. moly	7/16-in. moly	400	30	10	900	Satisfactory
66	B	Lincoln 660	1/8-in. moly	7/16-in. moly	375	35	10	800	Satisfactory
67	B	Lincoln 770	1/8-in. moly	7/16-in. moly	375	35	10	800	Satisfactory
68	B	Linde 80	1/8-in. moly	7/16-in. moly	375	35	10	800	Best to date, flux removal easy
69	B	Linde 20	1/8-in. moly + 10% Ni	3/8-in. moly	385	35	9	600	
70	B	80 coarse, 20 mesh	1/8-in. moly + 10% Ni	3/8-in. moly	385	35	9	600	
71	B	80 med. 20<>60 mesh	1/8-in. moly + 10% Ni	3/8-in. moly	385	35	9	600	Tests 69–76 represent an attempt to discover the affect of mesh sizes of flux upon weld properties. No correlation was established.
72	B	80 light <60	1/8-in. moly + 10% Ni	3/8-in. moly	385	35	9	600	
73	B	50%-80, 50%-770	1/8-in. moly + 10% Ni	3/8-in. moly	385	35	9	600	
74	B	Linde 50 x 12 x 150 coarse	1/8-in. moly + 5% Ni	3/8-in. moly	385	35	9	600	
75	B	80 coarse	1/8-in. moly + 5% Ni	3/8-in. moly	385	35	9	600	
76	B	Linde 50 x 8 x 48 fine	1/8-in. moly + 5% Ni	3/8-in. moly	385	35	9	600	
77	B	Linde 50 x 8 x 48 fine	1/8-in. tungsten	3/8-in. moly	385	35	9	600	Tests 77–81 represent attempt to lay down tungsten beads on moly plate. The tungsten melted with fair bead appearance but penetration with the moly base plate was nil.
78	B	80 Medium	1/8-in. tungsten	3/8-in. moly	385	35	9	600	
79	B	Same as 74	1/8-in. tungsten	3/8-in. moly	410	33	9	600	
80	B	80	1/8-in. tungsten	3/8-in. moly	410	33	9	600	
81	B	80	1/8-in. tungsten	3/8-in. moly	500	36	9	600	
82	B	80	1/8-in. moly	1/8-in. moly	485	33	9	400	Porosity
83	B	80	1/8-in. moly + 10% Ni	1/8-in. moly	485	33	9	400	Longitudinal crack
84	B	Mix 38	1/8-in. moly	1/8-in. moly	400	31	9	400	Good
85	B	Mix 37	1/8-in. moly	1/8-in. moly	400	31	9	400	Good
86	B	80	1/8-in. moly	1/8-in. moly	400	31	9	400	Good
87	B	.....	Hastalloy hand welded with d.c. reverse polarity						Cracked
88	B	.....	Inconel hand welded with d.c. reverse polarity						Cracked
89	B	80	1/8-in. moly + 10% of 18% Co, 82% Ni	3/8-in. moly	485	35	9	400+	Satisfactory — Constant arc conditions on tests 89–98
90	B	80	1/8-in. moly + 5% alloy as above	3/8-in. moly	450	34	9	500+	
91	B	80	1/8-in. moly + 10% alloy as above	3/8-in. moly	450	34	9	500+	
92	B	80	1/8-in. moly + 5% Co	3/8-in. moly	450	34	9	500+	
93	B	80	Cobalt	3/8-in. moly	435	35	9	500+	
94	B	80	Same as 89	3/8-in. moly	450	35	9	500+	
95	B	80	Same as 89	3/8-in. moly	450	35	9	500+	
96	B	80	1/8-in. moly	3/8-in. moly	500	36	9	500+	
97	B	80	1/8-in. moly	3/8-in. moly	450	35	9	500+	
98	B	660	1/8-in. moly	3/8-in. moly	450	35	9	500+	
8†	Butt weld	660	1/8-in. moly	3/8-in. moly	410	35	9	600 preheat 1300 postheat	Fair, some subsurface cracks
T	T weld	80	Same as 89	1/8-in. moly	415	32	9	600 preheat 1300 postheat	Welded both sides of T, good
U	Overlap weld	80	Same as 89	1/8-in. moly	415	32	9	600 preheat 1300 postheat	Welded both sides of lap, good
U_1	T weld	660	1/8-in. moly	1/8-in. moly	415	32	9	600 preheat 1300 postheat	Porous, flux removal difficult
V	Butt weld	80	Same as 69	1/2-in. moly	425	30	9	1000 preheat 1300 postheat 1000 preheat	Very good. Comparable to steel
W	T weld	80	Same as 69	1/2-in. moly	425	30	9	1300 postheat 1000 preheat	Very good. Comparable to steel
X	Overlap	80	Same as 69	1/2-in. moly	425	30	9	1300 postheat 1000 preheat	Very good. Comparable to steel
8_1	Butt weld	80	Same as 69	1/2-in. moly	425	30	9	1300 postheat	Fair, some weld cracks observed

* Having been unable to establish arc stability on 1/2-in. base plates in the prescribed series of tests and time, this size was abandoned for heavier material with an immediate improvement in weld appearance and arc stability and a virtual disappearance of burn-throughs.

† Welds 8 to 8_1 were made with material preheat to 600 or 1000° F. and postheated by placing in a reducing atmosphere furnace immediately at the conclusion of weld and slowly cooling to room temperature. Initial postheat temperature was 1300° F.

Fig. 4 Test 23 (7 ×)

Fig. 5 Test 23 (200 ×)

Flux

In arc welding metal in air, it is necessary to protect the molten metal from atmospheric oxidation which would ordinarily be quite rapid. This is especially true of molybdenum which oxidizes rapidly above 400° C. Fluxes are used for this purpose.

One type of flux, frequently composed of silicates and carbonates protects the molten metal by the liberation of neutral or reducing gases (CO, CO_2, H_2, N_2, etc.) upon the thermal decomposition of its constituents.

A second type of flux, such as might be used in the submerged arc-welding process with which we are concerned, is almost wholly composed of various oxides. Since it becomes fluid sooner than the metal being welded, it protects the molten metal by floating on top and forming a barrier to the air. It also dissolves oxides that may be formed by the molten metal.

This second type of flux with which we will be concerned hereafter must also satisfy other requirements.

Fig. 6 Test SM (7 ×)

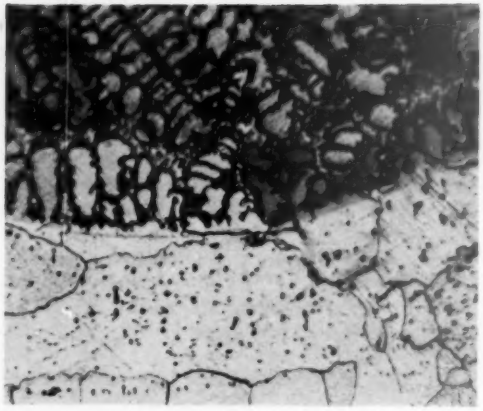

Fig. 7 Test 84 (200 ×)

It must be of the proper viscosity: if too low, it may run off the weld quite readily leaving the metal exposed too soon; if too high, it may not cover the metal properly or dissolve oxides readily. It must have a coefficient of expansion as different as possible from the metal so that it separates easily from the weld on cooling. It must present a suitable electrochemical potential to oxides that may be formed; basic to acidic oxides; acid to basic oxides. It must be stable to the passage of electric currents of high amperage; it must be homogeneous so as to prevent voltage fluctuations.

A consideration of just these few requirements will indicate the extreme difficulty of satisfying them all simultaneously and the development that must have gone into those that are, at present, standardized for iron and steel welding.

Molybdenum is metallurgically very different from commercial steels. It would be thought that the fluxes that are commercially available for steel would not satisfy any of the above listed requirements for molybdenum. Nonetheless, it was with these steel fluxes that we started. It was soon found that these were not entirely satisfactory in that their melting points were too low. There was also an interaction with the molten moly which made the removal of the slag residue extremely difficult and incomplete. The flux did, however, exert an oxide dissolving action since the metal under the slag was always much cleaner than that adjacent to the slag.

An attempt was then made (Tests 24–37) to devise fluxes based on chemical theory and fact that might be more suitable for molybdenum. These new fluxes were much less satisfactory in all tests. We attributed these results to two factors. Whereas the commercial steel fluxes are made by melting together the constituents and then pulverizing to the desired mesh size, our fluxes were

mechanical mixtures of the various constituents. These mixtures were observed to give much less arc stability and greater spitting than the regular steel fluxes. Their compositions will be found in Table 2.

Table 2—Special Flux Mixtures

1—44 SiO_2, 17 CaF_2, 39 MnO_2	18—25 CaO, 25 MgO, 50 No. 660
2—44 SiO_2, 17 CaF_2, 28 CaO, 11 MgO	19—25 CaO, 25 BaO, 50 No. 660
3—50 CaO, 50 TiO	20—50 BaO, 50 No. 660
4—50 No. 660, 50 Silica	21—95 No. 660, 5 Nickel
5—90 No. 660, 10 Ferco-manganese	22—95 No. 660, 5 Cobalt
6—90 Silica, 10 Ferrochrome	23—95 No. 660, 5 Iron
7—50 No. 660, 50 Sand	24—95 No. 80, 5 Nickel
8—90 No. 660, 10 Ferro-chrome	25—95 No. 80, 5 Cobalt
9—45 No. 660, 45 Silica, 10 Iron Oxide	26—95 No. 80, 5 Iron
10—80 No. 660, 10 Nickel, 10 Sand	27—90 No. 660, 5 Iron, 5 Nickel
11—80 No. 660, 10 Cobalt, 10 Silica	28—90 No. 80, 5 Iron, 5 Nickel
12—90 No. 660, 10 Cobalt	29—90 No. 80, 10 Cobalt
13—90 No. 660, 10 Iron	30—85 No. 660, 15 Nickel
14—80 No. 80, 10 Nickel, 10 Iron	31—85 No. 80, 10 Nickel, 5 Cobalt
15—90 No. 660, 10 Nickel	32—85 No. 660, 10 Nickel, 5 Cobalt
16—80 No. 660, 10 Iron, 10 Nickel	33— } (Numbers not used, ori- 34— } ginally assigned to 35— } particle sized fluxes; 36— } tests 70–76.)
17—40 No. 660, 50 No. 80, 10 Iron	37—60 No. 80, 40 Nickel
	38—80 No. 80, 20 Nickel

Realizing that the regular steel fluxes have a long history of development behind them and not obtaining any quick indication of the direction which should be followed, from the few new flux mixtures prepared, it was decided that further and more precise investigation would be both time consuming and beyond the scope of these exploratory tests.

Thus, we returned to the use of two of the major steel fluxes, Lincoln No. 660 and Linde No. 80, with the realization that they were, at best, a compromise for the present.

Size of Filler Rod

As is known, the submerged arc process utilizes a consumable filler rod. The automatic feed head at Kellogg was designed for $^1/_8$–$^5/_{32}$-in. diameter rod. For uniform results, $^1/_8$-in. diameter moly rod was used exclusively. For several tests this wire was plated with varying thicknesses of nickel, iron, nickel-cobalt or cobalt. Tests 77–81 were run with $^1/_8$-in. tungsten rods.

Thickness of Plate

The first tests were made on $^1/_8$-in. plate. A lot of $^1/_8$-in. seconds were immediately available at the time the program was started and this size was one of considerable interest. However, it was found that "burn-throughs" frequently occurred on this thickness. When a "burn-through" occurs, a hole is formed through which the filler rod protrudes and exerts a cutting action on the plate. This also results in very erratic power conditions. Accordingly, it was decided to abandon $^1/_8$-in. plate and shift to heavier sizes. Tests 1–57 were on $^3/_{32}$–$^5/_{32}$-in. plate; tests from 58 on were on $^3/_{16}$–$^1/_4$-in. plate. This shift to heavier material resulted in disappearance of burn-through and stabilization of arc, and such successful welds as were made thereafter were with material $^3/_{16}$ in. or thicker.

There are two commercial processes for processing molybdenum metal. One fabricates from a pressed and sintered metal, the second from a cast metal. All molybdenum used in these tests was pressed and sintered material as manufactured by the Westinghouse Electric Corp.

Pre-Heat

Tests 1–5 were made without any preheat of the molybdenum sheet. However, with the incidence of cracked beads it was apparent that severe stress would occur if molten molybdenum (2600° C.) were deposited on base metal at room temperature. A small gas-air combustion chamber was then constructed and the plates were welded after preheating above the chamber. Most of the preheat temperatures were between 400 and 1000° F. The final series of actual welds following Test 98 were performed on plate that was both preheated and postheated in a closed box, flushed by nitrogen, and all inclosed in a gas furnace.

Rate of Travel

The first beads were made at 15–20 in. per minute. There are velocities that are used on comparable steel thicknesses. However, it was found that the base metal did not retain enough heat at these rates to alloy sufficiently with the weld metal. The slower speeds gave better penetration and less stress cracking, particularly on the thicker plate. Accordingly, it will be

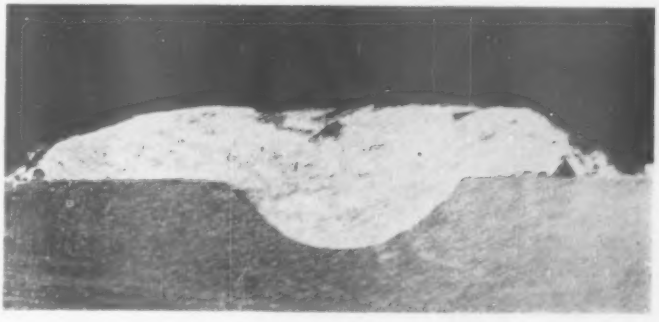

Fig. 8 Test 82 (200 ×)

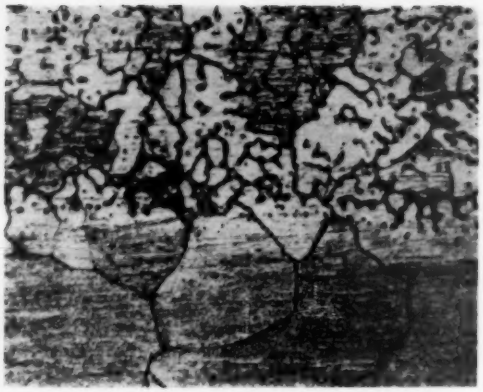

Fig. 9 Test 89 (300 ×)

seen (Table 1) that more moderate speeds of 8–10 in. per minute were used on later tests.

Current and Voltage

The current determines the rate of melting of the fed filler rod. Thus an increase in current will increase the deposition of rod as a given rate of travel. It will also increase the heat in the weld area and will give greater penetration. On $^1/_8$-in. plate, currents consistently were less than 400 amp., while on heavier plate, most of the readings were over 400 amp. for comparable speeds.

Direct-current reverse polarity was used throughout based on the experience and recommendation of Kellogg Co. engineers although a. c. is slightly more popular industry-wide.

The voltage exercises an effect on the bead width, a wider bead resulting from higher voltage. Unintentionally for the operator, the voltage may also vary the deposition of filler rod since the distance between the filler rod and the base metal is maintained constant, for a given preset voltage, by a special automatic control which regulates the feed by translating any variations in voltage across the welding zones with compensatory variations in the operation of the rod-feed motor. It was observed that, when a shift was made to thicker plate with consequent fewer burn-throughs, the voltage stabilized and much more uniform beads resulted.

Surface Appearance

One of the more discouraging features of these welds was a poor surface appearance as compared to surfaces normally seen on steel welds. This appearance is illustrated on some of the photographs appended to this paper.

This appearance improved considerably on the weld beads that contained 5–15% alloying elements (Ni, Co or Fe). Part of this appearance in the 100% moly welds was attributed to the lack of plasticity in pure moly. One of the effects of the rough surface was the entrapment of the flux slag, making its removal extremely difficult.

However, it was found that the surface appearance could not be surely correlated with weld porosity or stress cracks in the base metal, both of which could occasionally be found in microsections of welds having a satisfactory surface.

Although the base metal adjacent to the weld was subjected to oxidizing temperatures, no detrimental oxidation was observed.

Microsections

Microsections were made of typical welds as the welding program proceeded. These sections served primarily to indicate the presence of cracks and porosity not evident on the surface. This was particularly true of inert-gas arc welds. Photomicrographs were made on a Bausch & Lomb Metalloscope and the structure was brought out with an etch in a 50/50 solution of potassium ferricyanide and potassium hydroxide.

DISCUSSION OF TYPICAL BEADS AND WELDS

Figures 1–3 show most of the difficulties encountered in submerged arc welding of molybdenum using straight moly filler wire and standard commercial fluxes, as-received. It should be emphasized that the large grains shown in the base plate on this and subsequent photographs are not common to prime molybdenum plate but are typical of the over-annealed secondary plate that was convenient for experimentation. Penetration and shape of bead are fair. Yet even this cross

Fig. 10 Test U (7 ×)

section shows blow-holes, probably entrapped gases or flux constituents unable to escape to the surface due to the lack of melting range and plasticity in pure molten molybdenum. Figure 2, a longitudinal section of a similar weld, has a great number of these large blow-holes. Figure 3 shows in addition a multitude of smaller inclusions or pores whose exact history has not yet been determined.

In addition, welds made under these conditions frequently had a lack of penetration, large dendritic grains in the weld-metal, considerable porosity and a tenacious adherence of flux to the surface of the weld. These welds might be improved by increasing the current significantly, but such an increase would introduce other problems in the moly wire feed which must carry this current. On the credit side, several welds were made (such as S and U_1) which were of passable surface appearance and could serve as satisfactory joints where porosity and tensile strength were not critical.

After more than a score of weld beads with molybdenum only present, it was decided to try a moly bead on a mild-steel plate to observe the degree of wetting that should result from diffusion of dissimilar metals. This bead (Fig. 4) showed excellent penetration, density, a good surface appearance and ease of flux removal. These improved qualities were attributed to the plastic range of the weld metal resulting from the solution of iron into molybdenum to form an iron-molybdenum alloy as in Fig. 5. At a later date, an iron weld bead was made on a molybdenum plate with similar results (Fig. 6) although the penetration and degree of alloying were less due to the higher conductivity and melting points of the molybdenum plate.

On the basis of this improvement through alloying, a series of test beads were prepared in which nickel, iron or cobalt, or a combination of these, was introduced into the melt either through adding the alloying metal as a pure powder form to the flux or by plating the alloying metal onto the consumable molybdenum electrode. Both methods were found to work equally well to produce dense weld metal with better penetration, greater uniformity and fewer cracks than was experienced with molybdenum alone.

Consideration of the binary systems of metals involved indicates that these alloyed weld beads will be satisfactory for most high-temperature applications where molybdenum would be required. It is not as clear, however, whether the corrosion resistance of such deposits is comparable to pure molybdenum and tests are at present being made to obtain such data. Prior research* indicates that such alloys may have desirable corrosion properties.

Figures 7 and 8 show the effect of the addition of such an alloying element, in this case nickel, to the weld bead through modification of the flux or welding rod.

Figure 8 is a low-power magnification of the weld bead of No. 7; of particular note is the good density, penetration and shape.

Figure 9 illustrates a microsection of a weld bead laid down with a plated moly rod. The alloy dilution is about half of that of Nos. 7 and 8 but here again is shown the good density and penetration of alloyed beads.

Figures 10 and 11 illustrate cross sections of actual tee and butt welds made with plated moly rods in which the alloy in the weld is about 10% by weight. These are typical of the welds that were made with proper care on test pieces up to 1 ft. long and $^3/_4$ in. thick.

INERT-GAS ARC WELDING OF MOLYBDENUM

Over the past two years, various tests have been made both by the writer and others in Bloomfield and by the Westinghouse Welding Research Department in East Pittsburgh to arc welding molybdenum pieces together in an inert-gas atmosphere. In this process a nonconsumable tungsten rod serves as one of the electrodes, the work as the other electrode.

Butt, tee and overlap welds have been attempted with both an argon and a helium atmosphere using both a. c. and d. c. Such welds invariably show large grains, porosity and frequently have longitudinal weld cracks if the joint design is such as to introduce excessive cooling stresses or if the material being welded is thicker than $^1/_4$ in. On some, the surface appearance is good but this is belied by a microsection. A typical microsection is shown on Fig. 12 and a typical macro-

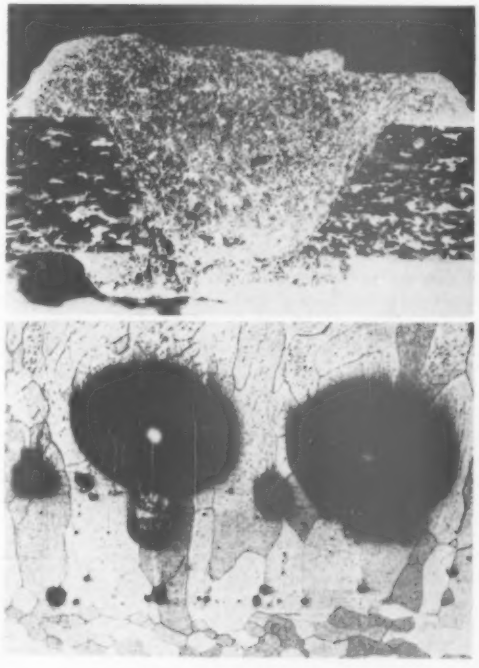

Fig. 11 Test S, (7 ×)
Fig. 12 Heliarc weld (75 ×)

* Paper RP1834, National Bureau of Standards.

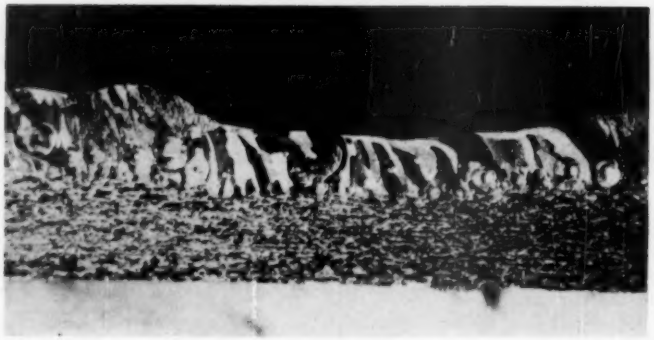

Fig. 13 Heliarc weld (3 ×)

Fig. 14 Heliarc welded furnace muffle

section on Fig. 13. The porosity can be greatly minimized by rewelding the joint although this will further recrystallize the adjacent base metal.

Considerable success has been experienced, however, in fabricating furnace muffles and similar closed boxes with plate material $^1/_8$ in. or lighter when using a lip, edge or corner construction as on Fig. 14.

Attempts have been made to heliarc "spot-weld" $^1/_8$-in. molybdenum sheets with scant promise.

Essentially the same may be said of atomic hydrogen welding as of inert gas welding. The results will vary some with the particular construction under consideration since the heat generated in the atomic hydrogen process covers a wider area whereas the heat in the inert-gas arc-welding process is more concentrated. Both processes are useful, however, where tack welds only are required, and a very considerable number of molybdenum assemblies are in use which have been tack arc welded and where these assemblies are supported by other structural members such as molybdenum furnace windings.

MANUAL ARC WELDING

During the course of our investigations at the Kellogg Co., several attempts were made to manually arc weld molybdenum plates with a flux-coated molybdenum rod. The fluxes were those commonly used on steel welding rods, removed by chemical solution and rebaked onto the moly. These welding trials were unsuccessful.

The flux coatings (gaseous) did not protect the moly from oxidation either during transfer from the rod to the workpiece or on the workpiece. A great deal of spitting was observed with very slight transference of metal. Until a suitable flux is developed, this method must be abandoned.

Several welds were tried with flux coated hastalloy and inconel welding rod on moly plate (see tests 87–88, Table 1). These showed longitudinal cracks although comparable in outward appearance to normal steel welds. Since there was no demand for such joints, this was not investigated further.

SUMMARY

1. For the bonding of pure molybdenum to itself, mechanical, brazing and resistance welding methods hold preferred positions.

2. Where design or weight considerations render the above methods inadvisable, some promise is held for arc welding, particularly submerged arc welding. Present limitations of submerged arc welding are development of a suitable flux, a better preheat and postheat cycle and applicability to material $^1/_4$ in. or heavier only. Inert-gas arc welding can be used on certain edge or tee welds with material substantially less than $^1/_4$ in. thick. A further advantage of arc welding to be considered is its convenience for field as well as factory applications. Manual arc welding is not held to offer any promise.

WELDING METALLURGY—Iron and Steel

The Society has revised the Welding Metallurgy book originally published in 1940. The book has been brought up to date and a wealth of new material added. This book is being reproduced serially in* The Welding Journal. *Copies in attractive imitation leather covers are available at $2.50

by O. H. Henry, G. E. Claussen and G. E. Linnert

Chapter 5
THE STRUCTURE OF METALS

Knowledge gained through studies of the structures of metals has been of notable help in the development of our modern metals and alloys. Yet metallography, the study of metals with a microscope, might be considered as being in its infancy. An even newer tool for studying the structure of metals is the X-ray diffraction camera. By examining metals through metallographic and radiographic means, we can predict many of the properties of a particular material from its structure; tensile strength, hardness and structural uniformity being typical examples. In welding it often becomes important to know the structural changes brought about by the localized heating and cooling.

ATOMS

Everything is composed of atoms. An atom consists of a nucleus and a number of orbital electrons. All electrons are alike, electrified particles of negative charge weighing 10^{-27} grams (10^{-27} = 0.000000000000000000000000001 gram, that is, a thousandth of a quadrillionth of a quadrillionth of a gram; there are 454 grams in a pound). Electrons account for only a very small fraction of the weight of an atom. The nucleus is made up of protons, particles of a positive charge weighing 1.00758×10^{-24} grams, and neutrons, which carry no electrical charge and weigh 1.00893×10^{-24} grams. The greater part of the weight of the atom is, therefore, concentrated in the nucleus. Different types of atoms differ in the size of nucleus and in the number of orbital electrons. Elements can be listed in order of their atomic weight starting first with hydrogen which has an atomic weight of 1.0081, second would be helium with an atomic weight of 4.003, and so on through lithium, beryllium, etc. The size or weight of an atom is a very important factor in metallurgy because it affects its behavior in metal crystals. The number of electrons surrounding the atom nucleus and their pattern is also important because this determines many of the physical properties and chemical characteristics of the element. At present, we have recognized 95 different types of atoms or elements, but now that man has learned to split atoms to release atomic energy and rearrange atom particles it appears that additional new elements will be created before long and added to the list.

GASES AND LIQUIDS

In the fluid condition, whether a gas or a liquid, two or more atoms frequently combine to form molecules. The atoms or molecules move freely among themselves. In a gas there is a lower limit to the closeness with which the atoms or molecules can be packed by low temperature or high pressure, but there is no upper limit. In a liquid, on the contrary, the atoms are practically the same distance center-to-center from each other as they are in solids. However, the atoms of a liquid may move freely among themselves and, as a result, the fluid is mobile and yields readily to the slightest pressure.

CRYSTALS

Since the atoms or molecules of a fluid move freely in all directions they possess very little ordered arrangement. In a crystal, atomic arrangement takes the place of disorder. A well-formed crystal possesses geometrical form; it is bounded by a number of plane surfaces, which are inclined to one another at characteristic angles. These planes are parallel to planes upon which the atoms are distributed throughout the crystal.

The arrangement of planes in a crystal is called the space lattice, a two-dimensional simplification of which is shown in Fig. 20, which applies to a cubic crystal, shown at the right-hand side of the figure. The atoms are at the points of intersection of three planes; that is, at the intersection of two lines in the lattice shown on the left-hand side of the figure. In addition to simple cubic crystals, there are body-centered cubic (having an extra atom located at the very center of the cube), face-centered cubic (having six extra atoms—one located in the center of each face), rhombic, hexagonal, and other types.

The space-lattice arrangement of crystals is important for two reasons: (1) It shows that the properties of a crystal will be the same along the same type of a plane, but different along different types of planes. For instance, the resistance to corrosion will be different if one cube face in Fig. 20(*b*) is exposed to the corroding

Fig. 20—Diagrammatic Sketch of a Crystal Space Lattice and a Simple Crystal
(a) (Left) Simple, two-dimensional example of a cube space lattice
(b) (Right) Cubic crystal

medium than if the diagonal plane of the cube is exposed. (2) The electrical and magnetic forces which knit the atoms together tend to prevent movement. Hence, crystals are harder and less mobile than all other types of atomic aggregates.

The shortest distance between atoms in metal crystals is measured by means of X-rays and varies with the composition of the crystal and its temperature. The closest approach of atoms in most metal crystals is about 3 to 6 $\times 10^{-8}$ cm. (about 0.00000002 inch). The closest approach results from a balance of attractive and repulsive forces between the atoms. Beneath the surface of a crystal the field of force surrounding an atom is entirely in equilibrium with the neighboring atoms.

Growth of Crystals

An atom at the surface of a crystal is not surrounded on all sides by neighbors. It, therefore, possesses available energy which is directed outwardly from the surface of the crystal. The crystal thus possesses surface energy, by means of which it can attract other atoms to itself, and if the environment is suitable, it can grow. The surface energy, and therefore the capacity for growth, is different depending upon the type of plane that is exposed. The cube faces usually possess the greatest capacity for growth in cubic crystals. The polyhedral form of free crystals shows that they grow with different velocities in different directions; otherwise they would be spherical.

Crystals grow by addition of thin layers of atoms to their faces. The atoms for growth may come from metal vapor (gas), liquid metal, ionic solution (for example, electroplating), or solid metal (recrystallization). Growth from liquid and solid metal is important in welding. Before discussing freezing and recrystallization, we will recall two facts about metal crystals:

1. The space lattice or crystal structure of a metal depends upon the element or elements present and on temperature (pressure can be neglected for metals and little is known about the effect of environment). Since the atoms in a crystal are held together by forces, it is easy to see that temperature, which affects the energy of the atoms, and the size of the nucleus and number of electrons in the atom are the two vital factors determining whether the atoms can be in equilibrium in a cubic arrangement or in a hexagonal or other arrangement. If two or more elements are present simultaneously in a crystal they may each exist as independent crystals; for example, crystals of nearly pure iron existing side by side with crystals of nearly pure copper in an iron-copper alloy. Under these circumstances we say that the two metals are practically *insoluble* (practically because our analytical technique is not sufficiently sensitive to prove complete insolubility of any two substances). If, however, the mixture of two or more substances crystallizes to form but one type of crystal, the elements involved are either in some sort of *combination* if the resulting crystal is different in type from the lattice of any of the elements involved, or are *soluble* in each other, if the resulting crystal is of the same type as one of the elements. Solubility can be complete or can be partial to any degree. An example of combination is iron and carbon, which combine to form iron carbide, a compound found in many steels. An example of a pair of elements which are soluble in each other is copper and nickel. Practically complete insolubility is exemplified by solid iron and solid lead.

2. The crystal structure of a metal determines its mechanical properties to a surprising extent. Body-centered cubic crystals, Fig. 21(*a*), such as alpha iron and tungsten, are characterized by high yield strength and limited cold workability. Face-centered cubic metals, Fig. 21(*b*), such as copper, are characterized by lower yield strength but greater capacity for cold work, to mention but two of the properties affected by crystal structure. If we reflect on the difference in arrangement

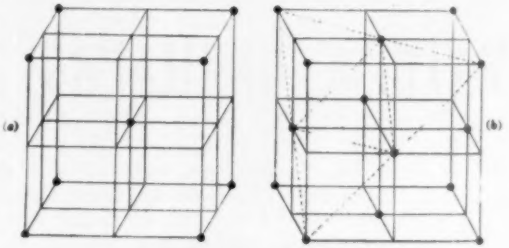

Fig. 21—(a) (Left) Body-Centered Cubic Crystal. (b) (Right) Face-Centered Cubic Crystal

of planes in the different types of crystals and remember the deformation of metal crystals is allowed because slippage occurs between the atomic planes that are farthest apart, we can easily understand the effect of crystal structure on mechanical properties.

How a Crystal Grows from the Melt

We have seen that the atoms of a liquid metal move freely among themselves. When, as we cool the melt, it reaches the freezing point, some groups of atoms fit themselves into the correct position to form a minute crystal called a nucleus. Although we know the nuclei form at the onset of freezing, the manner in which the atoms of the nucleus come together is one of the unexplained occurrences in nature. A split second before the nucleus forms, all of the atoms move freely among themselves. A split second afterward there is a bit of elastic solid in the melt.

Once the nucleus has formed, the crystal grows by additions of sheets of atoms on the growing planes. The type of planes upon which growth occurs depends a great deal on the rate of growth of the crystal. The rate at which metal crystals grow from the melt usually is proportional to the rate at which heat is withdrawn. For a cubic crystal, such as iron, the crystal grows out into the melt in three directions at right angles, Fig. 22, corresponding to the six faces of a cube. The resemblance of

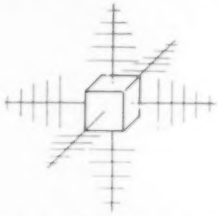

Fig. 22—Dendritic Growth of Crystals

crystal growth to a pine tree with its branches has given rise to the term *dendrite* to a growing metal crystal. Unlike salt and other substances which often crystallize from water solutions as compact, well-shaped crystals, metal crystals grown in the melt have a pine tree, dendritic appearance. If the entire melt solidifies to form a *single crystal*, it will have the shape of the interior of the crucible, and will occupy slightly less volume than the liquid. Although the atoms of a crystal are slightly closer together than in the melt (they are farther apart than the melt in bismuth), the crystal has practically no capacity for flow in the sense that a liquid has.

Examine a glass of cold soda water from which the carbon dioxide is being evolved as tiny bubbles as the liquid grows warmer. The bubbles form at the walls of the glass, from which they become detached by buoyant force and rise to the surface. The gas is evolved on the wall for two reasons: First, the glass, being in contact with the air, is warmer than the water. Second, there are minute peaks and valleys on the surface of the glass, which have high surface energy and therefore favor physical and chemical changes which require a little excess energy to set them off.

There is a similar situation in the freezing of molten metal. The heat is abstracted from the crucible through the walls. Convection ordinarily maintains the surface of the melt at the highest temperature. Consequently, crystal nuclei first form at the walls and bottom of the crucible, ingot mold, or weld groove, Fig. 23.

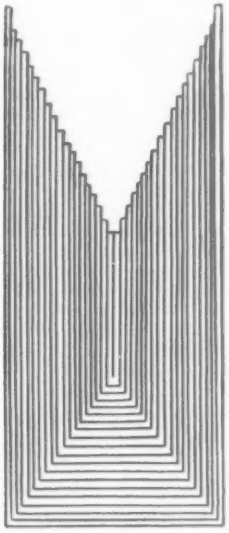

Fig. 23—Stages of Freezing of Metal in a Mold
See also Fig. 119, in which, at the left, crystals have formed at the sides and bottom, at the right, these have grown into columnar crystals

When the crystals have grown to cover the mold wall, the remaining liquid is, in effect, contained in a mold consisting of its own crystals. These crystals continue to grow into the melt until all the liquid is used up. The resulting ingot is said to exhibit *ingotism*, and the crystals which have grown in one direction only from the wall are called *columnar* crystals, because they are long and thin. Any shrinkage cavity is called a *pipe*.

Since nuclei have formed at a number of points along the wall, the solid consists of a number of crystals and is known as a polycrystalline solid. Generally the main planes in any one crystal will be at an angle to the planes of adjacent crystals; that is, the crystals of a polycrystalline solid have different *orientations*, Fig. 24, which is nearly always the case in cast, rolled, or welded steel.

The grains have irregular curved boundaries instead of straight boundaries with sharp corners, for the reason that numerous branches of a dendrite do not grow at equal rates. The ends of the branches of a given crystal therefore reach the ends of the branches of other crystals at varying distances from the axis of the crystal, Fig. 25.

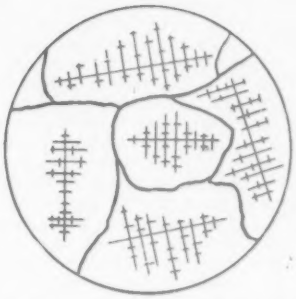

Fig. 24—The Individual Grains of a Metal Grow from Individual Nuclei and Dendrites

Let us now analyze crystallization from the standpoint of heat. We know that when a substance freezes it evolves heat. Conversely a crystal absorbs heat when it melts. As soon as a crystal nucleus forms, it gives off heat, which tends to offset the temperature drop in its vicinity. The heat evolution tends to stop further growth of the crystal and to favor the formation of new nuclei, which explains the rarity of large single crystals of metal.

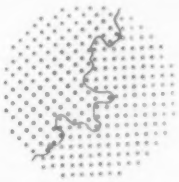

Fig. 25—Boundary Between Grains of Different Orientation

The heat evolution also arrests the drop in temperature of the melt, which is in accordance with our knowledge that the freezing of a pure material occurs entirely at a single temperature, the melting point. When all the liquid has solidified, the temperature once again falls, Fig. 26.

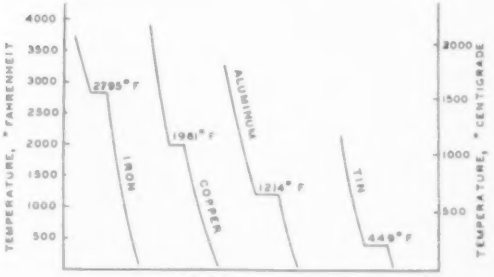

Fig. 26—During Cooling, the Temperature of a Pure Metal Remains Constant at the Melting Point Until All the Metal Has Frozen

One phenomenon in crystallization that has practically no importance in welding is undercooling. If a metal cools without agitation, the temperature may drop many degrees below the freezing point before crystallization occurs. Depending on the temperature, the melt may then crystallize from an extremely large number of nuclei, or if the temperature is sufficiently low it may not crystallize at all. The unusually "cold" liquid generally has extremely high viscosity and is called an *amorphous* (noncrystalline) solid. Borate fluxes and silicate welding

slags exhibit the tendency to undercool and become glasses. Liquid weld metal, on the other hand, never undercools to any extent because it is always in contact with metal crystals (base metal) of about the same composition. However, it is true that if liquid metals are cooled very rapidly, more nuclei form and there are more grains in the solid, hence the crystals are smaller than with slow cooling. Coarse grains in steel weld metal are undesirable, because they have only a fraction of the notch impact value of fine grains of the same composition.

It is a general rule, too, that the higher the temperature from which a liquid metal is cooling, the larger will be the size of the crystals in the ingot or weld. Overheating lowers the rate of cooling, which would tend to decrease the number of crystals, but overheating also may dissolve foreign particles, such as graphite in cast iron, which, if not dissolved, act as nuclei in the melt. Little is known about them, but if they exist in the melt, as they often do, nuclei form in advance of the growing columnar crystals. These new crystals grow in all directions, get in the way of, and stop the columnar crystals, and are called equiaxed crystals, because they grow the same amount along each axis. The solution of nuclei in melt depends on duration of melting as well as temperature. That is, although more salt dissolves in hot water than in cold, more salt will dissolve in ten minutes than in ten seconds. The short time during which weld metal is molten may lend importance to the time factor.

Metallography—the Microscopic Study of Crystals

In order to examine the structure of a weld under a microscope, a sample must be cut from the weld and heat-affected zone. The cut surface (usually not over an inch square) is ground or filed flat as the first step in securing a plane, polished surface, as scratch-free as possible (complete details for metallographic polishing and etching are given by ASTM E 3–46T and by the *ASM Metals Handbook*, 1948 Edition, pp. 159–162).

The as-polished surface, when examined at a magnification of 100 or 500 diameters (100× or 500×), is uniformly reflecting and featureless unless there are cracks, blowholes, or non-metallic slag inclusions in the specimen. Polishing pits and scratches should not be confused with the structure of the specimen. Occasionally a harder metallic constituent will polish in relief and thus will be visible in the unetched specimen.

Etching is performed by dipping the polished surface in a suitable reagent, which for steel is 5 per cent nitric acid in alcohol (Nital), for example. Metals which are resistant to acid attack, like nickel or stainless steels, may be etched electrolytically by having the specimen serve as the anode in a small cell arrangement. The etching reagent may do no more than reveal the grain size by attacking different grains to different extents. In this way one grain will reflect less light to the observer's eye than a neighboring grain and will appear darker. The etchant also may bring out the grain boundaries, and may attack one constituent at a faster rate than another. For instance, Nital dissolves ferrite in steel, but scarcely attacks iron carbide. Etching thus reveals grain size, and state of heat treatment and cold work, and distinguishes between different types of crystals that may be present.

Grain Size

When a liquid metal freezes, crystals usually grow from a large number of nuclei. Each crystal contains huge numbers of atoms rigidly held at fixed center-to-center distances. The many-sided crystals are heaped about, Fig. 27. The crystals may all have approximately the same size, or there may be a wide range of sizes. On the average, the crystals, or grains as they are generally called, may be large or small. Both size and size distribution have an important effect on the properties of steel and other metals. Grain size is measured by microscopic examination in the manner described in the preceding section, using a grain size eyepiece or a comparison chart.

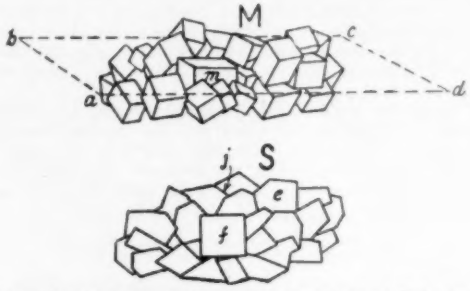

Fig. 27—Lack of Uniformity Among the Grains of a Metal (Richardson)
The lower diagram is a view from above the heap of crystals after it has been cut along plane *a-b-c-d* and the upper half removed

If we imagine that the dotted plane in Fig. 28 is the plane of the opaque metal specimen we are observing, we

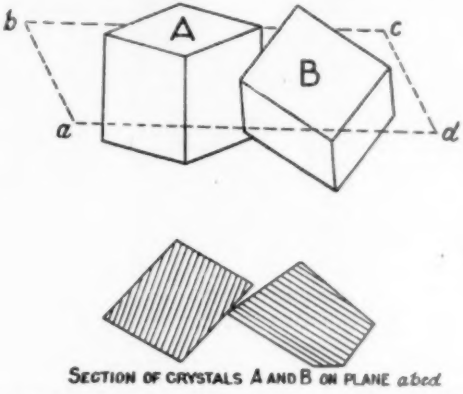

Fig. 28—The Structure Observed in the Microscope Is That of a Plane Cutting Grains at Random. (Richardson)

see, not the three-dimensional crystals, but the two-dimensional pattern of the grain boundaries. The plane we are examining may cut one grain through the middle, which will give the impression of a large grain, whereas another grain will be cut through one corner, which will give the impression of a small grain. In our specimen, we see, therefore, not the largest cross section of every grain, but some intermediate cross section, whose area, averaged over all the grains we see, is only a fraction of the maximum cross section of the grains. The observed average area is the best we can do and we, therefore, call it the grain cross section. The observed average area is then converted into grain size in terms of numbers of grains per square inch. In steel the average grain diameter may be in the neighborhood of 0.001 inch, and the grain size will be about 1,000,000 grains per square inch.

It is the custom to quote grain size as the number of grains in a square inch of specimen magnified 100 diameters. On the basis of 100×, 1,000,000 grains per square inch of specimen would become 100 grains per square inch of micrograph. A detailed description of the technique for rating grain size in metals may be found in ASTM Specification E 19–46.

How Grains Grow from Other Grains

If grains could not grow from other grains, annealing would have not nearly its huge effect in softening a metal, and welded steel would have not nearly its characteristic ductility. The grains of a pure solid metal may change over to another set under two conditions:

Grain Growth—Permanently distorted crystals or grains, upon their temperature being raised, recrystallize to undistorted equiaxed grains. The recrystallization temperature is the temperature at which distorted grains are replaced by equiaxed grains. The greater the degree of deformation, called cold work, such as by hammering at room temperature, the lower the recrystallization temperature. If the crystals or grains are distorted above their recrystallization temperature, they recrystallize at once. This kind of deformation is defined as *hot work*, as when steel is forged at a red heat.

Transformation—One type of crystalline structure, for example, cubic, may change to another type, say, hexagonal. A change of this sort, called a *transition* or *transformation*, occurs in a pure metal at a single temperature, the transformation point, in the same way that the change from liquid to crystalline solids occurs at a single temperature, the freezing point. At the transformation temperature we have, instead of nuclei forming in a melt, nuclei forming in a solid crystal. There are no crucible walls, but the original crystals have edges and corners that can supply the energy to set off the formation of new crystals. Hence, the nuclei usually form at the edges of the original crystals, called the grain boundaries. During cooling, the numerous new equiaxed grains grow until all the old grains have been absorbed, before the temperature falls once again. A similar process is repeated on heating but transformations usually are slower than freezing or melting because crystals are more rigid than liquid. If there are foreign particles in the pure metal, such as alumina in steel, they also may act as nuclei during a transformation. Undercooling, while more accentuated in a transformation than freezing, also leads to more complex situations than with freezing. In the absence of undercooling, the change in temperature during cooling through a transformation, has the same appearance as a cooling curve plotted during the freezing of the metal.

We will find that, if impurities or alloying elements are added to a metal, they affect the cooling curves during melting and freezing in ways that obey the same laws as the effects of these elements on any transformations that may occur. Transformations, as a matter of fact, are the exception rather than the rule. Nickel, copper, zinc, tungsten, and lead, for example, have no transformations. Iron, tin, and cobalt do, and a transformation at 1670° F, accounts for a great deal of the usefulness of iron.

Recrystallization, obviously, is different from transition or transformation. Recrystallization can occur only when cold-worked metal is heated to the recrystallization temperature. Transformations, on the contrary, occur every time a metal is heated or cooled through the transformation temperature. The product of recrystallization is a crystal of the same type as the original undistorted crystal. On the other hand, the type of crystal changes as a result of a transformation. Both transformation and recrystallization, however, have two elements in common: (1) The nuclei are extremely small, and (2) the transformation and recrystallization may be so controlled that the final grain size is finer than the original grain size.

Critical Points

In discussing transformations, we found that while cooling, heat is evolved during the transition of one type of crystalline structure to another. The metal also expands, at least in the case of iron at the 1670° F transition. On these two facts are based our methods of studying and controlling transformations, namely: thermal and dilatometric analysis. By thermal analysis, that is, by measuring the temperature of the metal during the passage of time, we determine evolutions of heat and are able to match them with transformations. Similarly, by observing any sudden change in length of our specimen during heating or cooling, we can also determine the temperature at which the transformation occurs. Transformation points, which we ascertain from (*a*) interruptions in the normal uniform rate of heating and cooling, or from (*b*) sudden changes in expansion or contraction of a specimen, are known as *critical points*.

Critical Points in Iron

We briefly mentioned that iron is an exceptional metal inasmuch as it undergoes structural transitions (displays critical points) upon heating and cooling. The remarkable behavior of iron on heating and cooling is pictured schematically in the "thermometer" shown in Fig. 29. A more detailed account of iron's behavior on heating follows:

At Room Temperature—Iron consists of body-centered cubic crystals, is ferromagnetic, and is called *alpha* iron.

At 1420° F—Loss of magnetism in alpha iron. For some time the non-magnetic body-centered cubic iron in the temperature range of 1420° to 1670° F was called *beta* iron; however, we do not now recognize this as a critical point because the loss of magnetism takes place over a very narrow range of temperatures and is not associated with a crystallographic transition.

At 1670° F—A transition from alpha iron (body-centered cubic crystals) to *gamma* iron (face-centered cubic crystals).

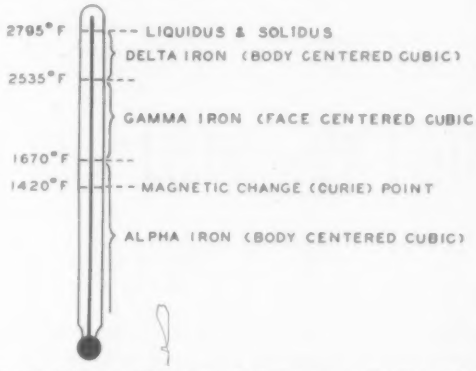

Fig. 29—Schematic "Thermometer" Illustrating the Behavior of Iron Upon Heating or Cooling

At 2535° F—A transition from gamma iron (face-centered cubic crystals) to *delta* iron (body-centered cubic crystals).

At 2795° F—Melting point. Disorder takes the place of atomic arrangement.

On cooling, these changes occur in the reverse order.

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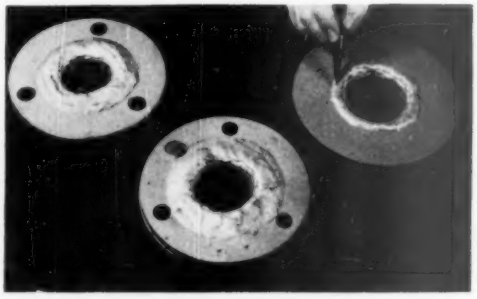
Steel Dies Inlaid with E Cu ALE

The dies shown below are typical examples of the use of E Cu ALE electrodes for inlaying draw edges. These electrodes are often used to build up worn die surfaces as well as the fabrication of new draw dies.

The specific dies shown were undercut for a finish machined build-up of $^{3}/_{16}$ in. using $^{5}/_{32}$ in. diameter Ampco-Trode 300 electrodes on reverse polarity, direct current. After welding, the surface was machined to the finished dimensions.

Ampco Metal (aluminum bronze) dies and Ampco-Trode composite dies are used extensively in the drawing and forming of stainless and low-carbon steels because they do not have the tendency to seize or gall thereby saving finishing time on the product, reducing scrap and increasing the service life of the dies.

These advantages are secured through the use of Ampco dies due to a combination of desirable properties which include high hardness, excellent wear resistance, unusual antifriction characteristics and resistance to high compressive loads. The average deposit hardness of Ampco-Trode 300 deposit is 300 Brinell measured with a 3000 kg. load.



Inlaid dies: as-welded

Data and photo courtesy Ampco Metal, Inc., Milwaukee, Wis.

Removing Buttonhead Rivets

by M. J. Harris

IT IS easy to remove buttonhead rivets with your standard cutting blowpipe and nozzle. Use the nozzle size recommended by the manufacturer for cutting steel 1 in. thick. Adjust the preheat flame in the usual manner. With the cutting oxygen off, preheat the top of the button for a little less than a minute. Then hold the nozzle parallel to the sheet or plate and slowly press down the cutting-oxygen lever. See Fig. 1.

M. J. Harris is Process Service Representative, The Linde Air Products Co., Buffalo, N. Y.

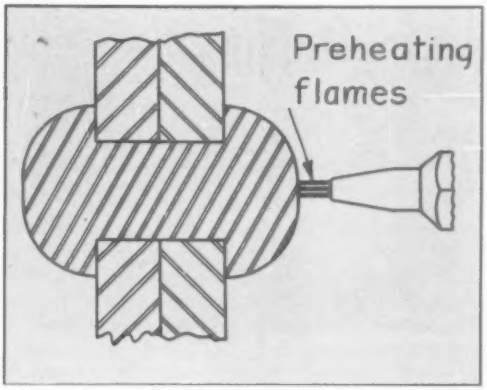


Figure 1

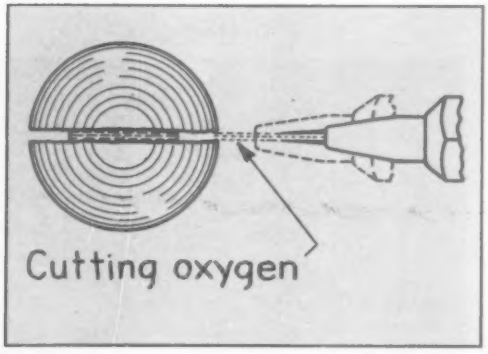


Figure 2

Cut a slot in the rivet head from the top of the button to the underside of the head. This should look like the screwdriver slot in a roundhead screw. By the time this slot is cut, the entire head will be preheated to the proper temperature. As the cut nears the plate, draw the nozzle back about $1^1/_2$ in. from the rivet. See Fig. 2.

The oxygen stream will then spread out slightly and will not cut through the layer of scale on the plate. Swing the nozzle in a small arc as the cut comes close to the plate. This slices off half of the rivet head. See Fig. 3.

Start at the original slot and swing the nozzle in the opposite direction to cut off the other half of the rivet head. The head is now cut off flush to the plate and you should be able to knock out the rivet with a few taps of your hammer. See Fig. 4.

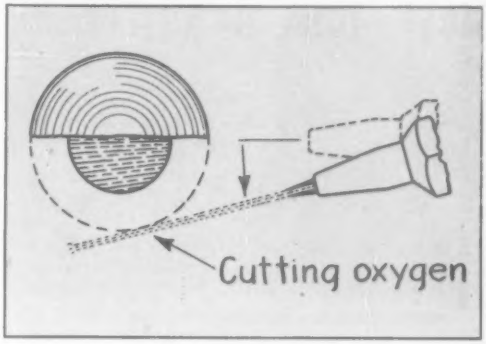


Figure 3

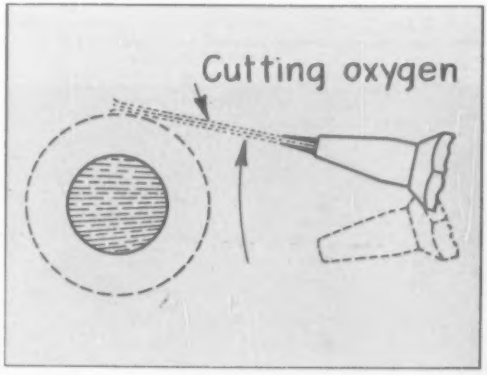


Figure 4

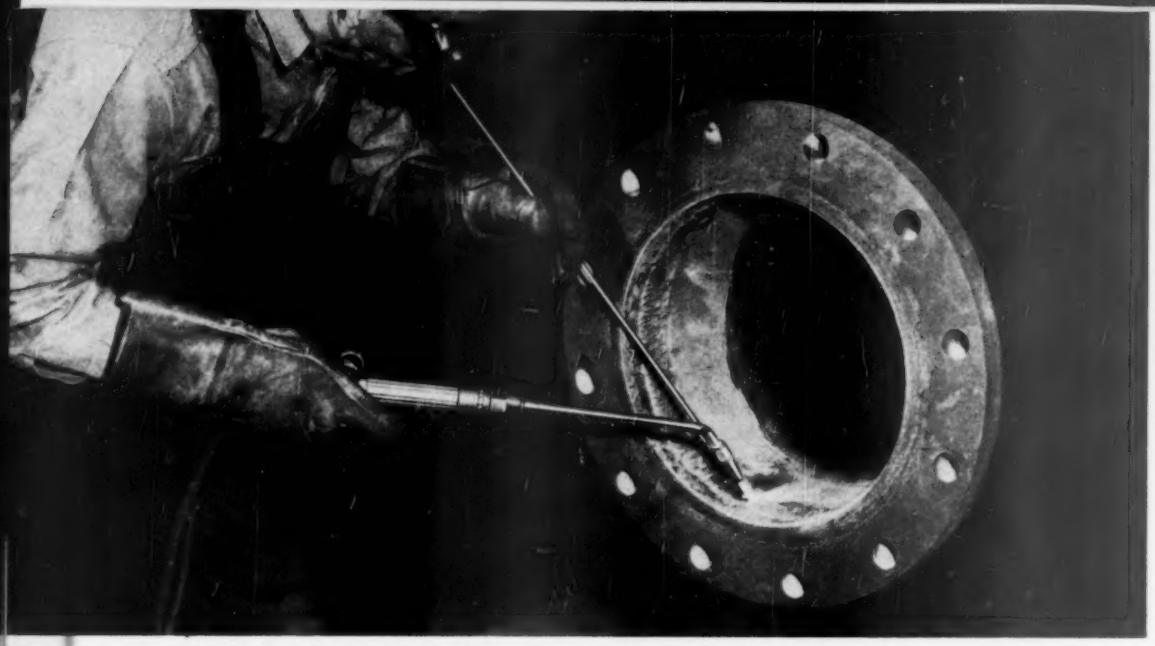


Fig. 1 The flange is being bronze welded to the pipe section in this illustration

More Jobs Repaired by Bronze Welding

Use this fast, economical repair method to get castings back on the job

by W. M. White

HERE are some typical bronze-welded repair jobs. In most cases the part was repaired and put back on the job in a few hours. New parts would have cost several times more than the repair costs.

W. M. White is Process Service Representative, The Linde Air Products Co., Chicago, Ill.

For large or small jobs, bronze welding is fast because you need little or no preheat. Often you can make the repair without dismantling the machine. Bronze-welded repairs, done under proper procedures, are as strong as the original part. For the best results use a good welding rod and flux. The rod should tin easily and solidify quickly. Bronze welding is also called braze welding.

Fig. 2 When $\frac{1}{2}$ to 2 in. of these cast-iron impeller blades wore away, they were rebuilt with bronze rod and put back to work

Fig. 3 Here is a cast-iron part that was repaired in 15 to 20 min. by bronze welding. It required only one standard length of welding rod

Fig. 4 This welding operator is repairing the base of a domestic hot water heater that had broken into eight pieces

Fig. 5 This large rock-crusher casting was bronze welded by two operators. They deposited 103 lb. of bronze-welding rod

Fig. 7 Rebuilding these gear teeth saved 6 mo. time. Forty-five teeth in each half of the gear were rebuilt with bronze-welding rod

Fig. 6 When the bolt holes in this truck wheel were stripped, they were filled with bronze-welding rod, then drilled and retapped

Fig. 8 A damaged flange on this transmission case was replaced by a new one cut from steel plate. The new section was bronze welded in a few minutes

Welding High-Carbon Steel

Manual hidden arc welding adapted to small, heavy nonuniform parts of high-carbon low-tensile steel

by Mark W. Sterner

ADAPTATION of the manual hidden arc-welding process to fabrication of certain small, nonuniform, high-carbon steel parts of the Moore Jackknife Cantilever Masts is effecting numerous production economies in the Lee C. Moore Corp. plant in Pittsburgh, Pa.

The manufacturer is currently using Lincoln Electric's "Manual Lincolnweld" equipment for fabricating the derrick's "feet" (Fig. 1); a unique sprocket arrangement (Fig. 2); and the adapters (Fig. 3).

In each of these operations, the time consumed in making these weldments has been reduced from one-sixth to one-fourth of that required under good hand-welding procedure. In addition, the quality of the welds now produced is proving far superior to most hand-weld deposits, especially where high-carbon, low-alloy and high-tensile steels are used.

The feet, which connect the tower to the base and serve as the revolving and anchoring agent during erection of the derrick, are fabricated from $^5/_8$-in. stock. The side pieces are scarfed by hand with a gas torch to a depth of approximately $^3/_8$ in., producing a somewhat rough fit-up by eliminating reinforcement. The hidden arc process is then brought into use to produce in a single pass the relatively heavy weld needed (Fig. 1). The work is rotated on a positioner but does not have to be accurately located on the face plate of the positioner. The operator can use the variable speed of the positioner or his own relative motion to compensate for any lack of uniformity in the joint. A speed of from 10–12 in. per minute is attained in this operation with an amperage ranging from 450 to 475 amp.

The unique sprocket shown in Fig. 2 is another unusual application of the process. The small assembly for the center sprocket is made with a 100% penetration joint between the two rings and the tubular piece. The welds are solid, free from all holes and cracks and the sprocket teeth are cut almost into the weld. The small assembly is positioned in a hole in the large sprocket and welded with fillet welds on both sides of the plate. Welds are normalized prior to machining.

Mark W. Sterner is Asst. Plant Supt., Lee C. Moore Corp., Neville Island Pittsburgh, Pa.

Fig. 1 This view shows a large weld being completed in the "foot" of a derrick, a part which serves as the sole connecting link between the base and the tower

Most of the strain is on this part during erection, which is completed in 2 min. The single pass weld in the $^5/_8$-in. stock is made with 475 amp. at a speed of 12 in. per minute

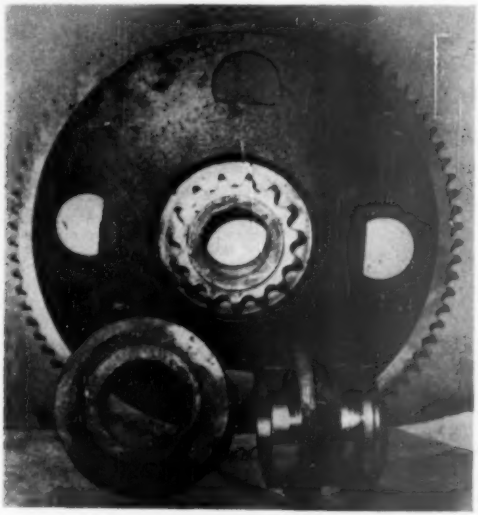


Fig. 2 A unique welded sprocket

Teeth in small sprocket in center are cut almost into the 100% weld, joining the ring to the tube

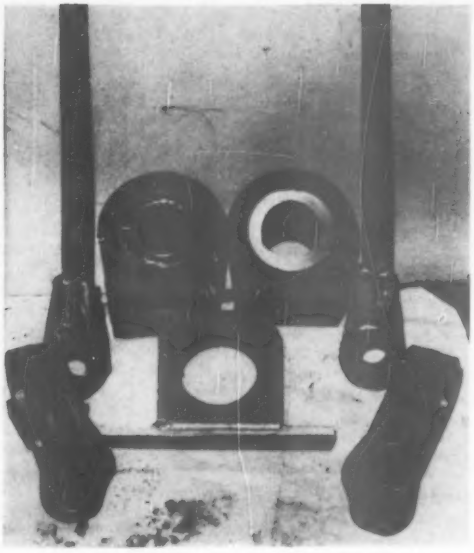


Fig. 3 These adapters connect shafts of the derrick at 90° to each other

The present welding method used on this operation completes the job in about one-fourth of the time required by regular hand-welding methods. It affords better appearance, much greater serviceability and is far more uniform than hand methods provide. Welding the sprocket is many times cheaper than producing it from forged blanks.

The adapters shown in the foreground of Fig. 3 are used to connect shafts of the derrick at 90° to each other. They are bent up from one piece with a $^1/_2$-in. filler plate in the fold which is then solidly welded. The deadeye in the center of the photo is made with both butt and fillet welds of deep penetration and the eye-bolts are fabricated from high-carbon round bar welded to eyes which are flame cut from plate.

Welds, made with this process in the fabrication of these vital parts, are free from slag and oxides. They are also hydrogen-free, providing high ductility and strength. Working conditions for the operator are substantially improved, also.

Welding Heavy Castings Restores Power Truck

Damaged by 150% overload

by J. A. Draxler

HOW welding saves time and money in repairing equipment and in keeping it on production work is illustrated by the following incident which occurred recently in an automobile body stamping plant.

With operations on full schedules day and night some machines often are overloaded; rated capacity figures are disregarded as long as they continue to operate.

So it was with an Elwell-Parker electric power-truck die-handler in this plant. Built in 1935 the truck's rated capacity was 50,000 lb. As autobody production was stepped up the truck was used regularly for 80,000 to 100,000-lb. loads.

At intervals the truck was used to transport 120,000-lb. loads on its platform in lowered, stationary position. Therefore, in an emergency it was assumed it could carry 125,000 lb., or a 150% overload.

This, too, it might have done if it had not been the victim of a freak accident in which both its arms which support its platform were broken off at their elbows.

The arms are chrome molybdenum alloy-steel castings, 13 in. wide, $3^1/_2$ in. thick, weigh 1750 lb. each. Their broadsides are formed at right angles midway in an over-all length of 8 ft. Assembled in the truck, the horizontal portions of the arms are in the main supports for the plat-

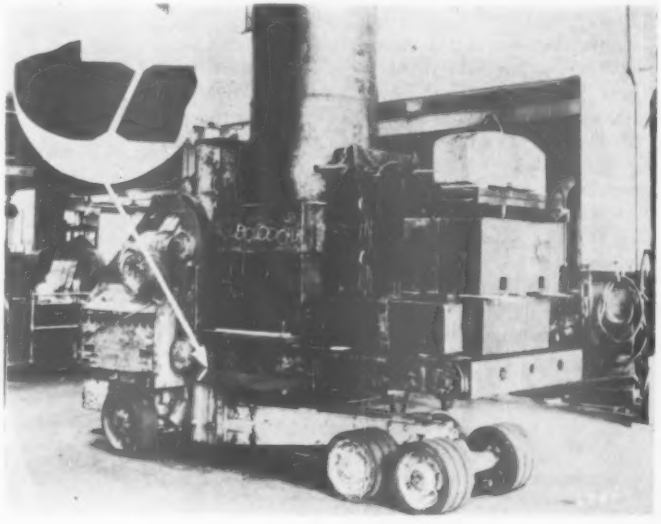


Figure 1

J. A. Draxler is Service Manager, The Elwell-Parker Electric Co., Cleveland, Ohio.

form, one under each side. The perpendicular lengths are attached to the elevator mechanism in the truck's upright columns.

Each of the arms broke off cleanly, clear through in about the same diagonal line across the elbow. There was no flaw in the castings or material; they had simply reached the limit of overstress.

The autobody plant had a number of trucks in service, but with production paramount this particular unit had to be back on the job in least possible time.

To make new castings corresponding to this 1935 model and to rebuild the platform would have taken 3 to 4 months. The cost was estimated at $3000. The time factor alone ruled this out.

Welding was the only alternative, and the truck was rushed to the maker's factory. Here welding practice and technique of the highest order play an important part in new truck construction. A plan was devised whereby the arms could be welded for strength and in positive alignment for functional operation.

First, certain retaining and connecting plates which had been broken were replaced and clamps and bracing also were used so that the entire platform assembly was held firmly together. Lower connecting pins were released permitting the platform to be swung out and away from the truck's upright columns. This brought the elbows about 3 ft. above floor level and free from all obstructions to welding.

Next the edges of the fractures were beveled down to 45° angles to make two opposing V's, with their points $^1/_8$ in. apart. Welding rods of the following composition were used: Carbon 0.30–0.40; Manganese 1.0–1.25; Molybdenum 0.30–0.40.

As alignment was essential for subsequent operation of the elevating mechanism the welding was done carefully to distribute heat and metal. Two welders were employed, one operating on each side of an arm. Two beads were welded along one side of the open V-shaped cut, then two along the other, each welder operating alternately, so that there could be no severe drop in temperatures to cause warpage in the finished work.

Forty pounds of metal was deposited in welding each fracture. Maximum thickness of the welded area was 4 in. Outer surfaces were rounded off as smoothly as possible in the welding operation, but they were not ground down.

This method proved entirely successful as demonstrated by a series of loading and operational tests at the factory. The welds are believed to be fully as resistant to overload and shock as the original castings. Practical use will prove this, as the truck is back in the autobody plant, again handling overloads.

Time out of service was one week, and the cost of the repair job, including replacement of broken angle plates was approximately $800. That is about one-fourth the cost and one-twelfth the time that would have been required if new parts had been ordered.

The "last straw" that broke the truck's arm was a stamping press which weighs 250,000 lb. The press had to be moved. Neither the truck nor an overhead crane was considered equal to the job, but it was decided to use them both, each sharing half the load.

The truck's platform was let down to its lowest point. The crane with cable lifted one end of the press. The truck moved up and that end of the press was lowered onto the outer end of the truck's platform. The idea was that the truck was to serve mainly as wheels for one end of the press, while the crane was to lift and maneuver the other end. When the crane attempted to lift its end of the press some part of its mechanism failed to function. The press dropped, with a severe jolt for the truck which then was bearing the greater part of the load. This heavy jolt on the outer end of the platform caused the arms to snap. However, the truck axle under the platform showed no distortion.

This illustrates the use and abuse to which power trucks often are subjected—and no reflection on users, because circumstances often require the extra strength the machines possess for various handling and maneuvering operations. It is evidence of confidence placed in them after many years of service.

Powder-Cutting

POWDER-cutting solved a difficult problem in refinery construction at a midwest refinery. The inner chamber of a large catalyst tower, erected some 5 stories high, proved to be $3^1/_2$ in. too long. It was made of 12% chrome steel, 1 in. thick. As well as shortening the column, it was also necessary to cut 8 circles in the inner chamber to allow heat to pass into the outer chamber while the entire tower was stress relieved in position. The holes were welded back after treatment.

By use of powder-cutting, the job was done in only two days. In all, some 70 ft. of chrome steel were cut. Powder-cutting was the painless solution to an aggravating problem.

In the illustration, the operator is using a cutting blowpipe with powder-cutting attachments to make the circumferential cut. One of the 8 holes cut for the stress-relieving operation is visible.

This powder-cutting process provides an easy method to cut material, such as stainless or high-alloy steels, oxidation resistant to the normal oxyacetylene flame. An iron-rich powder is blown into the oxygen stream from outside the preheat flame. This powder is heated to ignition temperature by the oxyacetylene preheat flame. The ignition of the powder creates a high-temperature reaction. As the cutting proceeds, a combined melting and fluxing action continuously removes any refractory oxides formed.

Data and photo, courtesy of The Linde Air Products Co., New York, N. Y.

President George N. Sieger's Address to the Members of the American Welding Society—Annual Meeting 1949

The detailed reports of our various officers and chairmen of our Standing Committees will show that our SOCIETY has progressed measurably during the past year (actually, an eleven-month fiscal period) in the order of increased and improved services of a nature requested by our Section Officers as representing our Membership. But financially we have suffered in comparable order to many other societies, and industrial organizations as well, whose income has been less than their expenditures.

As a result of concerted and timely effort by a number of sections, too few by far, and constant promotion by our National Membership Committee as well as Headquarter's activity in opening new sections and section divisions, we have been successful in nearly holding our past year's total membership numbers. But we have not realized the anticipated substantial gains in member numbers nor the added volume of paid advertising for our WELDING JOURNAL, both of which were required for balancing our 1948–49 budget—a budget comprehending expenditures necessary for providing the aforementioned services.

We have held with the Section Officers in the opinion that both new and improved existing services were mandatory. Therefore, unstintedly, we proceeded to: restyle and revise our WELDING JOURNAL; put added time and expense in the improvement of our *Welding Handbook*, Third Edition, now nearly ready for distribution; extend our Educational activities as fast as we could find personnel willing and with time to assume the obligation; design and produce a brochure for telling industrial executives the purposes, the scope and the objectives of our SOCIETY and why industry should support our activities—morally, physically and financially; redesign and produce a Year Book and new Membership Directory which would better serve our Section Managements needs; produce and issue an expanded and revised educational *Welding Metallurgy* book rewritten in a style acceptable to the shopman, the engineer and metallurgist—not any easy task; continue our agressive Section activity in the order of national officer and staff visitation as well as the development and institution of new Sections and section-divisions in areas not previously or presently so served; and many less discernible but very important and effective services in the manner of improved application forms, Membership and Section Officer services, etc.

We plan to continue with this pattern—to still further improve in a manner possible and commensurate with the support we receive from our Membership and our Sections. It is unfortunate that concurrently in a year devoted to such improvement and attended with the necessary added expense for such activity, industry found itself faced with the necessity of an economic retrenchment. Directly that retrenchment has resulted in reduction of publication advertising, a moratorium on promotional activity, slight but noticeable reduction in production and management personnel and constriction of expenditures which would not result immediately or quickly in dollar returns. Indirectly but effectively, these events have resulted in decreased income to our SOCIETY during the past year.

Therefore we are faced with the task of realistically analyzing the situation as we find it and, following the pattern of industry, constricting our coming year's activities in a manner that will both bring our operating costs within our anticipated income and still allow for providing our Membership and Section Managements the greater number of those services essential to their well being. Our National Finance Committee has prepared and your National Board of Directors have approved a 1949–50 operating budget designed for accomplishing that objective. During the coming year this budget will be re-examined quarterly and providential adjustments upward will be allowed if improving economic conditions allow, or necessary adjustments downward will be effected should such be indicated as necessary.

For a number of years I have believed, with one of our largest Sections, that were our SOCIETY to provide sponsorship and give full support to a supporting company membership enrollment plan, both our membership and industrial recognition would be greatly improved. I am very happy to report to you that during this year our Detroit A.W.S. Section has given proof that this belief had merit. Early in this past year our SOCIETY clarified the status of the plan, provided application forms which have simplified the registration of this type of group membership and gave full support to the project. As a result we are now experiencing a steady increase in the numbers of our Supporting Companies in those Sections which have wholeheartedly gotten behind industrial group membership enrollment. I strongly urge all of our Sections Officers to carefully study this group plan. If they will avail themselves of the assistance provided by the proper use and distribution of our new executive brochure, The American Welding Society—Scope and Objectives, and then promptly follow through with personal introduction of the "Supporting Company Membership Enrollment Plan" to industrial organizations in their Section's boundaries, they will succeed in those two vital requirements of our SOCIETY—increased section membership and section and national industrial support.

For many years I have advocated, with the support of the opinions of many of our Membership, that our WELDING JOURNAL incorporate a department containing articles of the "know-how" and "how-to-do-it" type, composed of a text understandable to both the production man and practical welder. These occupational fields are represented sizably in our membership numbers and it has seemed reasonable that a portion of our monthly publication should be devoted to the solution of their every day work problems. Cooperating fully in the process of WELDING JOURNAL restyling, our Journal Editor and Publication Committee have instituted the new department that so many of our membership have read and favorably commented upon "The Practical Welder and Designer." We want this department to be of value to our shop production membership. Necessarily it must consist of articles written by shop production people. To continue in its present quality and character we must have a constant source of such material supplied to us by industry. Our Editorial Staff does not write the JOURNAL articles. The JOURNAL is, by nature of its name a record of the opinions,

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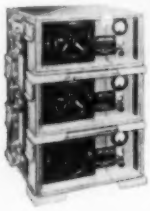

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the experience and the findings of industry and our membership. It is your "voice." We depend upon you for these articles and I urge your continued and increasing contributions so that, as a whole, our welding industry may be benefited by the experience of each of its membership.

I was greatly gratified at our last National Board of Directors Meeting to be able to present to your Board Members, for their review and approval, submissions by our National Educational Committee on the "Definition of a Welding Engineer" and "Definition of Welding Engineering." With greatest pleasure I announce to you that your National Directors unanimously approved the National Educational Committee's definitions. Our SOCIETY, by this action, registered its position. We are now able to approach engineering colleges, state licensing boards, governmental departments and industry in promotion of that objective necessary to the firm establishment of the recognized status of a welding engineer and welding engineering. I personally feel that this is an epic move by our SOCIETY; one that will result in increased strength and unity of objectives. Early this year our National Educational Committee cleared the path for institution of a vocational educational project. An experimental Vocational Educational Committee was established in the Detroit A.W.S. Section with approved scope of seeking the proper and adequate pattern in which our SOCIETY can effectively participate in vocational activity for the education of youth in welding and in preparation for continuation in welding engineering. As I have advocated for many years, our SOCIETY's interested and active participation in these fundamental programs, it follows that I am greatly encouraged to know that we are now acting in these directions.

This time last year I looked forward to a period of active work as your SOCIETY's President. Unfortunately that anticipation was not to be gratified. Soon after my assumption of the signal honor you bestowed upon me, the Presidency of the AMERICAN WELDING SOCIETY,' I was stricken with illness. And from January first of this year until but very recently I have been seeking and am happy to report that I have at last found, recovery. I am indebted to many for their assumption of most of my obligations. I am indebted to them for having helped to make my recovery possible.

I gratefully express my deep appreciation to our incoming President, O. B. J. Fraser. During my term as President and his as First Vice-President, he has, in the capacity of Acting-President, relieved me of all strenous duties. He has consulted with me throughout upon vital matters in policy and management and has gone out of his way to make my task an easy one. Our SOCIETY is indebted to him for the time taken from his regular activities, and I bespeak for him as President the fullest support of our Sectional and National Officers and our Membership. I am greatly indebted also to H. W. Pierce, incoming First Vice-President, R. S. Donald, continuing Treasurer and many of our National Directors who assumed additional responsibilities because of my illness. I am deeply appreciative to all of

them for their kind assistance and for their solicitous expressions for my rapid recovery during the past year.

As your retiring President I wish all of our Members continued success and our SOCIETY increasing strength and growth for accomplishing all those things that must be done for the benefit of our membership and our industry.

Welding Society Members at the Fruehauf Trailer Company Plant

Among the more interesting adventures during the recent Cleveland convention of the AMERICAN WELDING SOCIETY was a trip through the Fruehauf Trailer Co.'s plant at Avon Lake, Ohio. In Fig. 1, members are watching one of the interesting operations as a special machine accomplished 28 welds on a side panel for a corrugated trailer van. In Fig. 2 members are watching one of the early assembly line operations, the fitting of the tandem wheels on the underside. In Fig. 3 members are examining two of the new corrugated units fresh from the paint shop in the final operation on the line. The cover picture shows the spider construction on the 32 ft. huge frame.

Fig. 3

Fig. 1

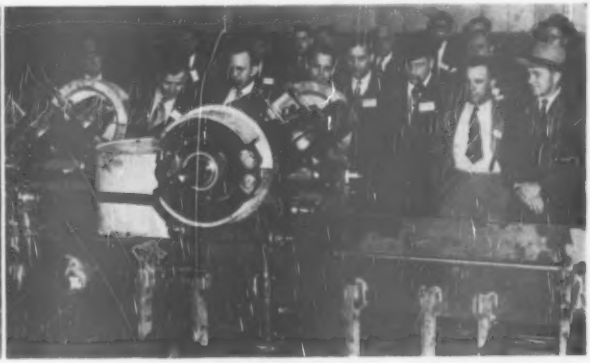

Fig. 2

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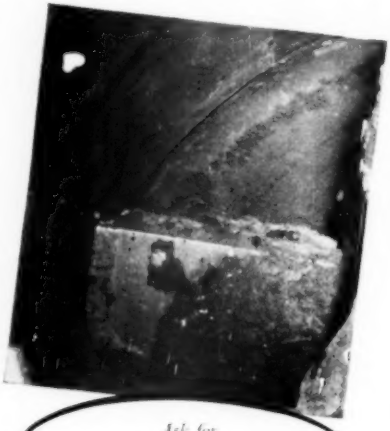

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a new edition of

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Material has been added to cover the new processes such as inert gas metal-arc welding; material has been added to provide greater coverage of the stainless steels.

A list of books is given at the end of each chapter for those especially interested in the subject covered by that chapter. Questions for school use are grouped together at the end of the book; they can be used for home study as well.

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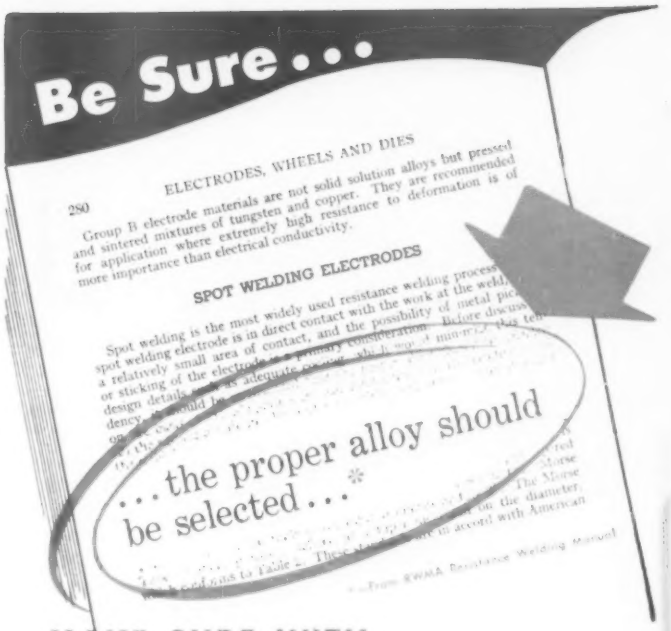

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Secretary Emeritus M. M. Kelly Honored at Luncheon

The Officers and chairmen of Committees of the AMERICAN WELDING SOCIETY, past and present, arranged a luncheon in honor of Miss M. M. Kelly, who retired October 1st as Secretary of the AMERICAN WELDING SOCIETY. The luncheon was held on Wednesday, October 19th, during the Thirtieth Annual Meeting of the AMERICAN WELDING SOCIETY in Cleveland. Some 50 of her friends were present. The master of ceremonies was R. D. Thomas of Philadelphia. Mr. Thomas stated:

"We are here to honor Marguerite Kelly for her long service as Secretary of the AMERICAN WELDING SOCIETY. The idea of having this meeting was not that of any one or two men but was the idea of a great many. The idea was generated like spontaneous combustion. We are here to let Miss Kelly know that we honor her, we respect her and we love her.

"Before there was a WELDING SOCIETY, Miss Kelly was Assistant to Dr. Comfort A. Adams. He, as you all know, was our first President and through him Miss Kelly became Secretary of the SOCIETY."

Mr. Thomas called upon Doctor Adams, first President of the SOCIETY, who on behalf of her friends presented Miss Kelly with a purse and a handsomely bound booklet of autographs. In making the presentation, Doctor Adams stated:

"To me this is a very pleasant duty and a very happy occasion as I look back upon thirty-one years of close association with our Guest of Honor.

"To me the greatest asset of long service is the accumulation of friends rather than of money. Miss Kelly, this Luncheon and the token to be presented to you are evidence of the numerous friends which you have made in your long and faithful service to the AMERICAN WELDING SOCIETY. We deeply regret that one of the prime movers of this event, our dear old friend, Bill Barnes, was detained because of illness. The other active member of the team was another old friend, R. D. Thomas.

"In tendering this gift, I am sure that I express the feelings of all concerned in wishing you many more years of happy life."

Following Doctor Adams presentation to Miss Kelly, Mr. Thomas called upon a number of the past presidents of the SOCIETY present as well as other officers. Each in turn, in his own way, paid tribute to the loyalty, efficiency and managerial ability of Miss Kelly. Some spoke in a humorous vein, others paid tribute to her charm and wit. It was one of the enjoyable occasions of the Annual Meeting.

In response Miss Kelly expressed pleasure at having so many of her good friends present. She admitted that when Doctor Adams first proposed her name to the Board of Directors to the office of Secretary she was frightened but determined to make good. She attributed such success as she attained to the encouragement of Doctor Adams, his kind consideration, and that of the many past presidents who followed him, as well as the Directors, committee chairmen and members of the SOCIETY. She paid special tribute to the Finance and Convention Committees, to the Sections and to a loyal staff. She mentioned the team work between herself and Bill Spraragen and overcoming many of the obstacles which confronted the SOCIETY in the early days. Miss Kelly expressed gratitude to all and to Bill Barnes and R. D. Thomas who arranged the Luncheon.

Board of Directors Meeting

A meeting of the Board of Directors of the AMERICAN WELDING SOCIETY was held in the Hotel Cleveland, Cleveland, Ohio, on Wednesday, Oct. 19, 1949, with the following in attendance:

Board Members: C. A. Adams, D. Arnott, L. C. Bibber, W. F. Boyle, J. J. Chyle, G. E. Claussen, A. F. Davis, R. S. Donald, O. B. J. Fraser, J. Grodrian, H. O. Hill, J. H. Humberstone, T. B. Jefferson, C. H. Jennings, C. I. MacGuffie, A. F. Moses, H. W. Pierce, G. N. Sieger, H. N. Simms, L. C. Stiles, J. B. Tinnon and R. L. Townsend.

Cleveland Section Representatives: C. T. Elder and J. F. Maine.

Staff: J. G. Magrath, F. J. Mooney and W. Spraragen.

Others: D. H. Corey, G. M. Trefts, J. R. Wirt and J. C. Wyss.

Call to Order

The meeting was called to order by President G. N. Sieger at 3:25 P.M.

Hazel Hakalow Memorial Resolution

Memorial Resolution for Mrs. Hazel Hakalow, deceased, was prepared by a Special Committee, consisting of Messrs. T. J. Crawford, J. D. Gordon and J. R. Stitt. This memorial resolution was read by the Secretary and, by vote of the Board of Directors, the resolution prepared by this Special Committee was adopted for the records of the Society and transmittal to the family of Mrs. Hakalow.

Expression of Thanks Extended to Retiring Board Members

Retiring President G. N. Sieger extended the appreciation of the President, Officers, Board Members and the SOCIETY to those Members of the Board of Directors now retiring for their valued services, namely, Messrs. D. H. Corey, W. F. Hess, R. E. Lorentz, Jr., J. F. Maine, E. L. Mathy, L. S. McPhee, G. M. Trefts and J. R. Wirt.

Vote of Thanks Extended to the Cleveland Section Members

The Board extended a vote of thanks to the Cleveland Section Officers and Members who did such a splendid job in handling the 1949 Annual Meeting activities in Cleveland.

Change of Chairmanship

At this point, Mr. Sieger turned the Chair over to O. B. J. Fraser, newly elected President of A.W.S. for the 1949–50 administrative year.

Appointments

Officers—Upon motion, duly seconded, the following officers were reappointed for the administrative year beginning October 1949: *Secretary,* J. G. Magrath; *Asst. Secretary and Asst. Treasurer,* F. J. Mooney.

Appointments of Committee Personnel

Upon motion, duly seconded, committee personnel, as printed in the December issue, were appointed to serve for the 1949–50 administrative year.

Designation of Officers to Sign Checks and Other Documents in Behalf of the Society

As prescribed by the By-Laws, on motion, duly seconded, it was voted to authorize the Treasurer and the President, and in the absence of either, the Assistant Treasurer, to sign checks, notes, receipts, acceptances, endorsements, releases, any and all contracts and other documents, in behalf of the SOCIETY.

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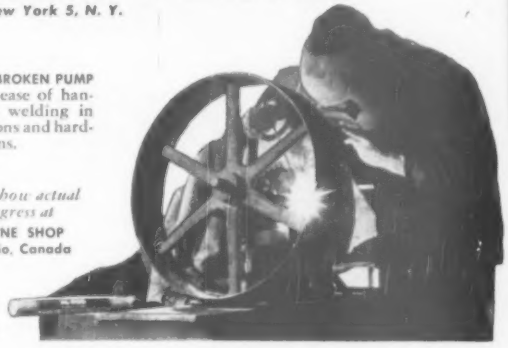

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Appointment as Assistant Editor of the Third Edition of the Welding Handbook

The Board of Directors approved recommendation of the Handbook Committee that J. I. Medoff be listed as Assistant Editor in the third edition of the *Welding Handbook*.

Time and Place of Next Meeting

The next meeting of the Board of Directors was set for Dec. 15, 1949, to be held at the Hotel Statler, New York, N. Y.

Hakalow Memorial Resolution

WHEREAS, the AMERICAN WELDING SOCIETY recognizes, in the death of Mrs. Hazel M. Hakalow, the loss of an active and valued member of the Society; and

WHEREAS, Mrs. Hakalow, as the only woman member of the Detroit Section, blazed a new path in the field of women's activities; and,

WHEREAS, her unstinted efforts in the work of the Section contributed materially to the success of the Detroit Section and thus to the growth of the SOCIETY; and

WHEREAS, her work, her cooperative spirit and her ever-cheerful manner endeared her to all; therefore be it

Resolved, that the AMERICAN WELDING SOCIETY, through its Board of Directors, hereby expresses its sincere appreciation for Mrs. Hazel M. Hakalow's services to the SOCIETY; and be it further

Resolved, that these Resolutions be spread upon the records of the SOCIETY, with expressions of sympathy and regret, and copies of these Resolutions transmitted to her parents, Mr. and Mrs. A. Heidi and to Richard A. Hakalow, her son.

A.W.S. Defines a Welding Engineer and Practice of Welding Engineering

Over a period of time the SOCIETY has received requests by the Membership to provide definitions of a "Welding Engineer" and the Practice of Welding Engineering. It appears that many of our Membership believed that a SOCIETY-sponsored definition would be very helpful toward securing greater recognition of the status of the welding engineer and the practice of welding engineering. They believed such would be influential in the order of consideration by State licensing bodies toward requests by individuals for professional licenses and consideration by educational institutions toward including greater welding engineering activity in their curriculum and granting of degrees in welding engineering.

About one year ago the A.W.S. Educational Committee was assigned the task of investigating existing definitions of industry and governmental bodies and arriving at its own definitions which it would then submit to the Board of Directors for consideration.

At the Sept. 22, 1949, meeting of the Board of Directors of the AMERICAN WELDING SOCIETY, held at the Hotel Statler, New York, N. Y., definitions submitted by the Educational Committee were reviewed and upon motion, duly seconded, approved by the Board of Directors. These definitions follow:

Definition of Welding Engineer: "A Welding Engineer is one who, by reason of his special knowledge of the mathematical and physical sciences and the principles and methods of engineering analysis, acquired by professional education and/or practical experience, is qualified to practice welding engineering as defined in the following paragraph."

Definition of the Practice of Welding Engineering: "The Practice of Welding Engineering involves a knowledge of three basic areas in engineering: one, the design of machines, structures and equipment as well as the design of suitable connections; two, the materials of engineering with particular reference to metals, gases and refractories; and three, the processes, procedures and equipment of the welding industry. The practice of welding engineering includes such professional services as consultation, investigation, evaluation, planning, design or responsible supervision of construction or manufacturing when such professional service requires the application of engineering principles and data."

Through the medium of this publication in THE WELDING JOURNAL, these definitions are submitted to all AMERICAN WELDING SOCIETY Members with a cordial request for their comments. Comments should be in letter form, addressed to the Secretary, AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y., and should be mailed prior to Feb. 15, 1950.

The CHAMPION of all general purpose electrodes

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GRAY DEVIL #2

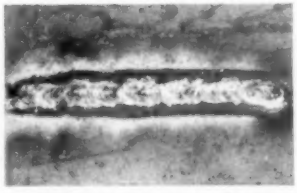
AWS CLASS E 6012

D. C. Straight Polarity (May be used with A. C.)

Welding supervisors have long sought an all-purpose electrode which would withstand high currents without loss of efficiency — THAT'S GRAY DEVIL #2!

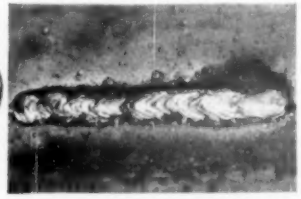
Operators have always wanted a straight polarity rod which could be used with plenty of heat without the usual penalty of excessive globular spatter — THAT'S GRAY DEVIL #2!

Welding engineers have required a general purpose, poor fit-up electrode which would consistently produce good quality welds of uniformly smooth appearance, excellent slag characteristics and ease of handling in all positions — THAT'S GRAY DEVIL #2!



Above: CHAMPION Gray Devil #2. Note absence of spatter at high amperage.

Below: Typical of many comparative electrodes tested. Note heavy globular spatter.



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THE CHAMPION RIVET COMPANY

CLEVELAND, OHIO — EAST CHICAGO, IND.

Employment Service Bulletin

Position Vacant

V-242. Resistance Welding Engineer. Progressive mid-western manufacturer of resistance welding equipment has opening for good classical and practical engineer. Must have degree, several years' experience and ability to carry on original independent development. Possibility of quick promotion to Chief Engineer. State full education, experience and salary expected.

Services Available

A-589. Superintendent, Supervisor or Foreman (Utility, Mechanical or Welding Activities); Training Supervisor; Inspector of Equipment, Materials or Welding Activities. Available for foreign service and travel. Can speak, write and read Spanish.

A-590. Welding Engineer—Metallurgist. B.S. in M.E. and M.S. in Metallurgy. Twenty years' experience in welding development, research and production. Tanks, code vessels, alloys, automatic processes. Desires position in production, development, research or sales promotion. Prefer Los Angeles area.

A-591. Graduate in Mechanical Engineering. Has Technician's Certificate in Welding and Metallurgy from large S. W. State College with several years' practical welding and hard-facing experience. Navy veteran, age 28, married with two children. Position desired with opportunity for advancement in shop or Engineering Department or in the teaching field. Available February 1.

A-592. Certified Electric, Acetylene and Hydrogen Welder. Age 25. Married. Two and a half years with the Experimental Research Lab. on jet propulsion at Wright Field, Dayton, Ohio. One year at Boeing Aircraft. Certified welder on aluminum and ferrous steels. Two years at American Overseas Airline, LaGuardia Field. Fabrication of ferrous and nonferrous steels. Two years at welding and engineering, Norfolk, Va.

A-593. Graduate Engineer, age 34. Twelve years' experience in administration, research and development, coating formulation and metallurgy. Desires position as Welding Engineer or allied situation.

Adams Lecture Series

Each year in order to honor the first President and Founder of the AMERICAN WELDING SOCIETY, an eminent authority is selected to give the Adams Lecture at the Annual Meeting of the SOCIETY. Six of such lectures have now been presented. They are available in reprint form with special covers. Individually and collectively they represent a contribution to our knowledge. Orders may be placed with the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. Price 50c per copy. Complete set including the 1949 lecture $2.25.

The Lectures are: E9.1, "Solid Phase Welding," by A. B. Kinzel, 1944, 22 pp.; E9.2, "Selection of Steel for Welding," by S. L. Hoyt, 1945, 10 pp.; E9.3, "New Frontiers in Welding," by W. F. Hess, 1946, 9 pp.; E9.4, "Structural Strength of the Welded Joint," by G. S. Mikhalapov, 1947, 16 pp.; E9.5, "Metallurgy of Covered Electrode Weld Metal," by G. E. Claussen, 1948, 15 pp.; E9.6, "Fatigue of Structural Joints," by W. M. Wilson, 1949.

BOUND VOLUMES OF THE WELDING JOURNAL

Bound volumes of THE WELDING JOURNAL for the years 1946, 1947 and 1948 may be purchased at a special price of $25.00 plus postage for the three (3) years as listed. The Journals are bound in attractive imitation black leather covers. Act now as this offer expires April 1, 1950. Orders may be placed with the AMERICAN WELDING SOCIETY, 33 West 39th Street, New York 18, New York.

A Subject and Authors Index for any or all of these years will be sent upon request.

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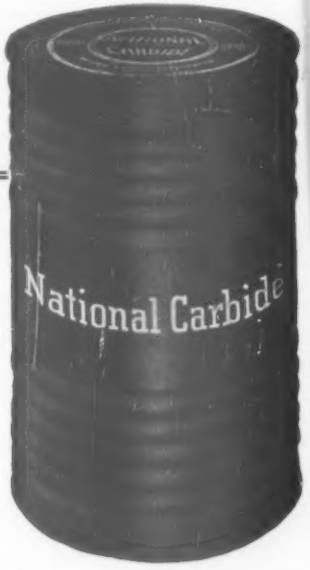

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NEWS OF THE INDUSTRY

Engineering Equipment Exposition

Dramatic demonstration of new equipment in all fields of engineering with the emphasis on live action will keynote the Fifth Annual Exposition of the Minnesota Federation of Engineering Societies which will be held at the Minneapolis Armory, Feb. 21–24, 1950, according to H. E. Palmer, President of the Federation. Mr. Palmer also stated that Brede, Inc., Convention Managers of Minneapolis, have been retained to take complete charge of the exhibits.

The guest register for previous years shows that interest in the Exposition is not confined to Minnesota alone but attracts men interested in new tools and tool design from states as far West as Montana and the neighboring states of North and South Dakota, Wisconsin and Iowa.

Exhibitors will have an opportunity to show their latest educational films in the Little Theater which has a seating capacity of 150. This service which is free to all Exhibitors provides a 16-mm. machine, screen and operator.

Stud Movie

More than a score of cost-cutting opportunities available to industry through the use of automatic stud welding are shown in a new 18-minute color sound movie "Split-Second Fastening," just completed for the Nelson Stud Welding division of Morton Gregory Corp., Lorain, Ohio. In addition to animated sequences which clearly explain the revolutionary stud-welding process by which fasteners are end welded to steel, the film shows how it is used in building construction, railroad shops, shipyards, automotive plants, the fabrication of electrical equipment and numerous other applications in practically all phases of the metal-working industry.

Bookings can be arranged by metal-working companies, engineering and architectural societies, contractors' organizations, business clubs and other interested groups by contacting local Nelson field engineers and distributors, or by writing Nelson Stud Welding Div., Lorain, Ohio.

Stevens Institute Is Given 330 Volumes

Stevens Institute of Technology has recently received 330 volumes on various technical subjects, Dr. Harvey N. Davis, president of the college, announced recently.

The Federal Shipbuilding and Dry Dock Co., Kearny, N. J., which has terminated operations, gave the school 308 volumes of engineering society transactions, bound technical magazines and textbooks, formerly part of its engineering library. Nineteen bound volumes of the AMERICAN WELDING SOCIETY JOURNAL from this group, were the gift of C. W. Bryan, Jr., vice-president and general manager of the shipbuilding concern. The books will be used at the Experimental Towing Tank and in the Mechanical and Metals Depts. at Stevens.

Another gift of 22 books from the New Jersey Chapter of the American Society for Metals was presented to the library of the new Peirce Memorial Laboratory of Metallurgy. Among the basic standard volumes on metallurgy contained in this group are: *Alloy Constructional Steels*, by French; *Electronic Methods of Inspection of Metals*, by Hamburg; *Fracturing of Metals*, by Bain and *Sleeve Bearing Materials*, by Dayton.

During the past year there has been a tremendous increase in the demand for books on metallurgy, Frances I. Duck, librarian at Stevens, said, and volumes from both donors will fill an acute need in this department.

Income of Metallurgists Tops All Engineering Groups, According to New National Survey

Metallurgy is the highest paid of the engineering professions.

This fact was established as a result of a recent National survey conducted by the American Society for Metals from its National headquarters in Cleveland, Ohio.

The survey, first of its kind ever made, also classified the professional metallurgist as to his title, class of work, responsibility over others, distribution of time, products made by his company, as well as salary bracket at different periods of employment.

This occupational analysis of the metallurgical profession, conducted by the metalworking industry's basic Society, establishes for the first time a separately defined status for the metallurgist. Previous statistics on this important member of the engineering profession have been in conjunction with mining engineers or other groups.

Here is the pattern and some of the significant results of the nation-wide investigation of the metallurgist's professional standing. Selecting better than 50% of the total metallurgists among the Society's 20,000 members, the questionnaire sought answers to specific questions about the metallurgist's background and his contribution to our industrial progress. Thirty per cent of those questioned sent back their answers, a high percentage, according to seasoned pollsters in the industrial field.

Income. The average income for metallurgists, according to the A.S.M. analysis, is $6567. The National average income for all types of engineering, according to the U. S. Bureau of Labor Statistics, is $4668. Comparisons with other professional incomes are equally impressive. The lawyer receives an average of $5719; the chemical engineer's annual average is $4320. The average yearly income of all college graduates in the U. S. is $4689, while the average yearly pay of all U. S. Workers is $2840.

Three factors were shown to affect a metallurgist's income—his responsibility, his college or technical training and the length of time on the job.

Aside from 6.5% of those queried who had succeeded to administrative and sales positions, the responsibility of metallurgical control over quality and production offered the highest income—a high of $35,000, with an average of $7221.

The second factor—that of technical training—shows that with a bachelor degree, the metallurgists income averaged $6601. A master's degree justified $6877. The metallurgist with a doctor's degree has an average yearly income of $9122.

The third influence came from experience or length of service. Metallurgists with one year out of college drew an average income of $3700. After five years on the job, the average went to $5500. Ten years' experience advanced the income to an average of around $6500. Twenty years after graduation, the metallurgist was averaging $8100. The peak average income is reached thirty years after receiving a college degree—$9000. From this point the average income gradually decreases.

Work Categories. Thirty-two per cent of those responding were employed by the producers of basic metals. Fifty-one per cent worked in industries which fabricate metals into finished products or parts. The remainder were engaged in various services to the industry.

Class of Work. Forty per cent of those queried were concerned with technical problems of production. Thirty-two per cent were engaged in technical research or development. The remaining 28% were concerned chiefly with technical contacts, management and distribution.

Titles. A majority of those questioned—61% gave their titles as metallurgists. Eleven per cent of this number were identified as Chief metallurgists. Seven per cent of the replies came from Material Engineers, while 4% were Production Engineers. Supervisors, superintendents, foremen and other operating personnel made up the balance.

Distribution of Time by Activities. Only in technical duties did any of the respondents devote all of their time. Thirty-one per cent of the total number spent 100% of their time on technical matters.

All of those questioned spent some of their time in this field. Only a single reply indicated less than 11% time in this activity.

National Welding Supply Association

Current issue of the official bulletin of the above Association, *Spatter*, indicates continuing interest of its membership. Twenty-one new members have "joined up."

Welding Plastics

American Agile Corp., of Cleveland, Ohio, announces the formation of their new Plastics Division which will be devoted exclusively to the welding and flame spraying of thermo plastics. This may be considered an entirely new innovation in welding application inasmuch as it is accomplished by the use of hot-gas welding guns plus plastic filler core material. The welding application is similar to the oxyacetylene gas welding method, but without a burning flame.

The Flame-spraying operation is done by means of a Flame-Gas spray type gun which is manufactured in but one size at the present time.

Agile Welding Guns are capable of producing welding heats of 280 to 650° F. and are remarkably effective and efficient in the welding of such thermo plastics known under the trade names of Saran, Polythene, Koroseal. The aforementioned brands are merely a few that can be adapted to this type of welding. Further detailed information can be had by writing American Agile Corp., 5806 Hough Ave., Cleveland 3, Ohio, attention of the Plastics Division.

Cobalt 60

St. John X-ray Laboratory, Califon, N. J., has just received a 350 millicuries source of Cobalt 60. This is a radioactive material to be used for industrial radiography in place of radium. Since Cobalt 60 has a smaller focal spot size than the equivalent amount of radium, better results can be obtained by the use of this radioisotope.

A separate building has been designated for the exclusive use of Co 60. The Company is also prepared to apply it on any field job.

Class in Theory and Design of Welded Structures

For the second time this class, sponsored by the Graduate School, United States Department of Agriculture, will be given next semester. Classes will be held in the General Services Bldg., 19th and F Sts., N. W., Washington, D. C., each Monday evening from 6 to 8 P.M. beginning Monday evening Feb. 6, 1950. The class will be taught by Nathan W. Morgan, Principal Highway Bridge Engineer, U. S. Bureau of Public Roads. A number of industrial and Governmental films showing various features of the welding processes will be shown during the course. The following is an outline of the course.

Literature, Specifications, Definitions, Symbols; Processes, Cutting, Equipment; Training, Qualification, Inspection, Safety; Testing; Structures, Failures; Difficulties; Physics, Metallurgy; Metals, Weldability; Filler Metal; Workmanship, Technique; Design, Details; Economy, Estimating, Cost; Final Examination.

Westinghouse Review

A special Mid-Century Review and Forecast Forum was held on Thursday, November 10th, in East Pittsburgh, Pa., by the Westinghouse Electric Corp., which was attended by a number of editors of technical magazines and daily newspapers. Some 13 or 14 forecasts were made by outstanding experts of the Company. Welding is to play an important part in a number of the departments. Special mention of the applications of welding was made by the Transformer Dept. and the Research Laboratory. For example, in the construction of transformer tanks, welding enabled the designers to overcome many difficulties due to leakage and to free the designers to make an oil-type transformer tank exactly suited to the job.

The Research Laboratory continues to study some of the less understood components of welding processes and to devise better and more economical processes and to determine the requirements of newly developed or applied metals. The arc and resistance welding processes are being studied as well as welding in controlled atmospheres.

Steel Research

The following are items contained in a review of current research by the U. S. Steel Corp.:

Late in the year, Carnegie-Illinois announced that after a decade of painstaking experimentation and tests, it is prepared for commercial production of low-carbon (0.03% max.) stainless steels. These new steels, which are especially useful in industry, have resistance to intergranular corrosion equal to that of 18-8 stainless steels to which columbium and titanium "stabilizers" have been added. Welding tests demonstrated that the low-carbon stainless steels can replace the stabilized types for applications, such as welding, that involve short heating times in the sensitizing temperature range.

First of its type on the rivers, a Diesel-electric tugboat was put in operation on the marine ways of the Carnegie-Illinois Clairton Works. Used as a harbor tug to shift barges which supply coal to the by-product coking plant—the world's largest—of this United States Steel subsidiary, the vessel is of all-welded steel construction, with ⅜-in. thick hull plates fabricated from USS Cor-Ten to take advantage of the resistance to atmospheric

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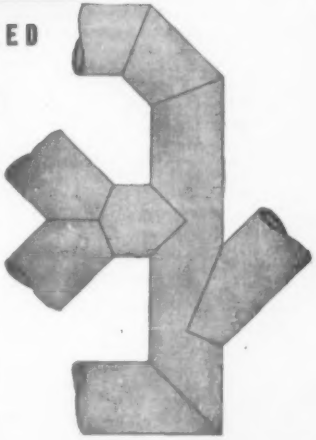

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EUTECTIC WELDING INSTITUTE
NEXT SEMESTER: FEB. 15, 1950

Eutectic's new welding institute is being opened in answer to the enormous demand for instruction in Eutectic's new welding techniques. Located at our modern plant at Flushing, N. Y., it will welcome our customers' welders and all who wish to profit by the new economies made possible through general use of Eutectic low heat welding processes. Metals you can learn to weld the most profitable way, for production and for repair: Aluminum, Stainless, Magnesium, Monel, Steel, Copper, Brass, Bronze, Die Castings

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SIZES 1/4 TO 300 KVA.
FOR MANUAL, AIR, MOTOR OR ELECTRONIC OPERATION,
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For Furnaces, Lighting, Distribution, Power, Auto Phase Changing Welding, and Special Jobs
AIR, OIL and WATER COOLED.
Sizes 1/4 to 300 KVA.

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corrosion and the weldability of this high-strength alloy steel.

On the west coast, United States Steel Products Co., applied Cor-Ten to the fabrication of 4400-gal. semitrailer gasoline tank truck tanks. The high strength of this material, permitting the use of thinner sheets, saves 1200 lb. in weight on each tank, providing a free ride for 200 gal. of gasoline on every trip.

Three active and one spare 25-ton Bessemer converters, all of unique, all-welded and stress-relieved design, are the core of the new steelmaking plant of National Tube Co., at Lorain, Ohio. The new continuous tube mill is expected to manufacture up to 18,000 tons a month of seamless steel pipe and tubing in a diameter range from 2 to 4½ in. A new blooming, bar and billet mill was also added to the Lorain facilities during the year, to round out earlier improvements. These consisted of a giant warehouse to house a continuous supply of the company's Lorain products, a concentration of butt-weld pipe facilities and new coal-handling and coke-making plants, including a coal research laboratory.

Champion Contest

The Champion Rivet Co. announces the following winners of the daily contest held at their booth during the National Metal Show held at Cleveland Public Auditorium from Oct. 17 to 21, 1949. The number of electrodes in the cylinder and the person with the nearest correct answer for each day was as follows:

Champion Rivet Company Booth

Oct. 17, 1123—R. R. Schier, Fawick-Airflex Co., Cleveland, Ohio.
Oct. 18, 1148—Lee Carter, The Lummus Co., Honesdale, Pa., and Bob Burger, Alcoa, Cleveland, Ohio.
Oct. 19, 1164—E. A. Koenig, The Yoder Co., Cleveland, Ohio.
Oct. 20, 1109—Carl F. Joseph, Central Foundry Div., Saginaw, Mich., and W. A. Bidlingmaier, The Truscon Steel Co., Cleveland, Ohio.
Oct. 21, 1186—I. S. Wishoski, "Industrial Heating," Pittsburgh, Pa.

The prize, a set of stainless steel steak knives, has been mailed to each of the above winners. The Champion Rivet Co. wishes to express their thanks to all who so willingly participated.

Forty-Six Billion Resistance Welds Help Auto Industry Set New Record

More than 46,560,000,000 resistance welds were required in producing this year's record automobile output, The Resistance Welding Institute, Cleveland, reported, recently.

This multibillion record of electric welding's contribution to the nation's transportation was announced following the disclosure that passenger car production reached an all-time high of 3,880,000 automobiles during the first 10 months of 1949. The average auto contains approximately 12,000 resistance welds with more than 8000 in the body alone, according to the Institute.

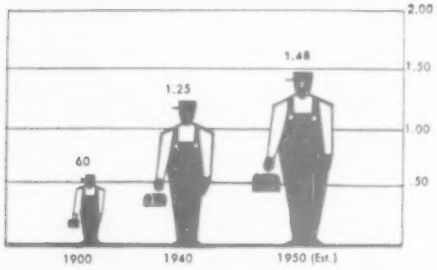
Now prominent as an assembly process in the fabrication of virtually all volume-production metal products, resistance welding scored its initial success in the automotive industry by making the assembly line possible. Industry authorities say that were it not for the high production obtainable through resistance welding, the modern motor car would cost at least several hundred dollars more, the Institute pointed out.

Sand Muller Plow Hardfaced

The plow blades in a sand mulling machine are exposed to one of the most severely abrasive operations in industry. In many cases they mull a total of more than 125 tons of foundry sand per day. In the machine pictured here, the wear was so severe that plows had to be replaced every four days on the average. As it takes two men 3½ to 5 hr. to remove old plows and replace them with new ones, replacement was an expensive maintenance item.

America's Future Prosperity depends on

Higher Production per Man-Hour



The basis of our well-being has always been closely allied with the *value of goods an hour's work will buy.* As the chart shows, this value has increased from 60c worth of goods in 1900 (at today's prices) to an estimated $1.48 worth in 1950. This value is bound to increase, and smart manufacturers know that *their* prosperity as well as the country's, depends upon their ability to produce more goods per man-hour expended.

here's how one manufacturer boosted production per man-hour eight times!

One of the world's largest producers of wheeled toys was faced with the problem of speeding up assembly of wheels. The assembly involved fastening two stamped wheel halves with 8 spot welds.

Instead of purchasing additional welders, training new operators and taking up valuable floor space, a special *multiple welder* was designed and built by Sciaky. The operator has only to load the gravity feed chute, press starting switch and then keep chute full. Finished wheels drop out the other side at the rate of 30 per minute!

Thus, only one operator welds more than 8 times as many wheels as formerly produced. Here is an instance where skilled use of resistance welding greatly *increased production* and *decreased unit cost.* For a complete description of this machine write for Bulletin No. 25B.

SCIAKY

THREE-PHASE

Sciaky specializes in both a complete line of standard welders, and in the design and manufacture of special units, tailored to your needs. You are invited to consult our Application Department without obligation.

Pioneers and Inventors of THREE-PHASE Resistance Welding Equipment

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Sand Muller Plow Hardfaced with Tungsten Carbide

To get longer service from these parts, hardfacing was tried. As an experiment, Amsco Tube Tungsite, 30–40 mesh, was applied—with sensational success. The useful life of the parts was multiplied at least 32 times. The above photograph was taken after four months of service with the original plows still in place. The foreman of the department estimated that they were good for at least two months more—a total of over six months. He also estimated that the Tungsite hardfacing would save the company approximately $390 in castings and labor alone—not to mention loss of production time—during the six-month period.

Amsco Tube Tungsite, the hardfacing rod used on these plows, is of the tungsten carbide type. Finely granulated particles (30 to 40 screen mesh in this case) are encased in a tube of mild steel. In welding, the tube casing melts to form a matrix for the hard carbide particles, thus creating an extremely wear-resistant surface. Tube Tungsite and Tungrod are supplied in a wide range of granulations, from 5–8 to 40–125 screen mesh.

300 Ton Trailer

Designed and built by the Eidal Mfg. Co., of Albuquerque, N. M., this mammoth 300-ton capacity trailer was fabricated with General Electric welding equipment. It is to be used by an oil company in moving rotary oil-drilling rigs and drawworks without disassembling. The original method of moving rigs required 30 days, it was said, but with this 72,000-lb. trailer the entire equipment can be moved in about 24 hr., at approximately one-sixth the cost. The framework of the giant trailer as well as the axle mountings were are welded.

300 Ton Trailer

4 to 5 Times LONGER LIFE

Dressing Time REDUCED BY TWO THIRDS

and here's the proof!

UNTREATED TREATED

At left... Ordinary carbon brazing tips ready for the discard after only 500 operations. At right ... Stackpole "F" treated tips AFTER 1300 SIMILAR OPERATIONS!

CARBON BRAZING TIPS

...with the famous Stackpole "F" Treatment

STACKPOLE'S recently developed "F" treatment for its Carbon Brazing Tips has resulted in units that operate at temperatures above red heat, require dressing far less often, and increase tip life four to five times that of untreated carbon by minimizing oxidation. Their resistance to cracking or spalling permits more radical temperature changes than is possible with any other material.

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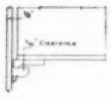

WELDING CONNECTORS

Saxe System Welded Connection Units for welded assembly

Saxe Units place in position and securely hold together structural parts to be welded.

As used in many welded structures they *eliminate all hole punching* producing an economical, rigid, safe and quickly erected structural frame.

"Write for 58 pg. Manual containing full engineering design information for welded structures."

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PERSONNEL

New Appointments by Metal & Thermit

Metal & Thermit Corp., New York, announces new appointments and transfers of personnel as follows:

Bernard W. Weber has been appointed Manager of its detinning and electrode manufacturing plant at East Chicago, Ind. Mr. Weber formerly was Manager of the Seattle plant of the American Can Co., with whom he started as a laborer in 1934, progressing through the jobs of mechanic, inspector, research worker, manufacturing general foreman and plant general foreman. He is an alumnus of Oregon State College.

W. S. Leinhardt, formerly General Superintendent of the East Chicago plant, is now at the Metal & Thermit executive offices in New York as Technical Assistant to the Vice-President of Production.

William C. Cuntz, formerly Manager of the company's sales office and warehouse in Pittsburgh, has been made District Manager at Chicago. Mr. Cuntz joined M & T in 1935 as Sales Engineer in the Thermit Dept.

Orville T. Barnett, formerly Manager of the Newark, N. J., office has been appointed District Manager at Pittsburgh. Mr. Barnett joined M & T in 1940 as Engineer of Tests in the Electrode Dept., having previously been Chief Inspector of Black, Sivalls and Bryson's pressure vessel plant in Oklahoma City.

Robert T. Brown, who formerly headed Technical Service on both electrodes and Thermit, has been made District Manager at Newark, N. J. Before joining M & T in 1943, Mr. Brown was Assistant Superintendent of the American Can Co. machine shop in Cincinnati, Ohio.

Bruton Made District Sales Manager

William C. Bruton has been appointed District Sales Manager for American Manganese Steel Division of American Brake Shoe Co., and Robert H. Elem has been appointed Pacific Coast Manager of the Welding Products Dept., according to an announcement by J. B. Terbell, Division Executive Vice-President.

Mr. Bruton, formerly Sales Engineer, first joined Brake Shoe in 1916. His territory covers the Pacific Northwest including the Yukon Territory and Alaska, and he will make his headquarters at the Division's plant in Oakland, Calif.

Mr. Elem, formerly Welding Engineer, is a graduate of the University of Southern California. During World War II he served with the Army Signal Corps in the Pacific area. He is a member of the American Society for Metals and the American Welding Society. He will make his headquarters at the Division's plant in Los Angeles, Calif.

J. P. Coughlin Manager of Field Sales

The appointment of J. P. Coughlin as manager of field sales, Welding Dept., Westinghouse Electric Corp., Buffalo, N. Y., was recently announced by J. O. Clevenger, manager of that department.

Mr. Coughlin was graduated from the University of Missouri in 1939, joining Westinghouse upon graduation. He subsequently served as welding sales engineer for the Southwestern district, headquartered in St. Louis. In 1942 he was commissioned in the Navy, serving as officer in charge of welding construction at several large shipyards.

In 1945 he returned to Westinghouse as manager of welding products, Agency and Specialty Sales Dept., East Pittsburgh. He held this position until his recent appointment as manager of field sales for the Welding Dept.

Wadley and Wicker Elected Magnolia Airco Vice-Presidents

M. G. Wicker and H. T. Wadley have been elected vice-presidents of the Magnolia Airco Gas Products Co., it was disclosed recently by J. R. Pryor, president.

Both Mr. Wicker and Mr. Wadley were district managers for Air Reduction Sales Co., a Magnolia Airco affiliate, prior to their promotion. Their sales territories, which included portions of the states of Oklahoma, Louisiana and Arkansas, will now be serviced by the Magnolia Airco organization. Mr. Wicker will continue to have his headquarters in Oklahoma City, Okla., and Mr. Wadley will remain in Shreveport, La. Both men have been with the Air Reduction organization in sales capacities for over 20 years. Mr. Wicker is a member of the American Welding Society.

Airco Announces Technical Sales Division Appointment

J. H. Berryman has been appointed assistant to the manager, technical sales division, it was announced recently by J. J. Lincoln, Jr., vice-president, Air Reduction Sales Co. He will assist Scott D. Baumer, manager, this division.

Mr. Berryman was graduated from John Hopkins University in 1935 with a B.E. in mechanical engineering. He joined Bethlehem Steel at Sparrows Point, Md., and remained with them as assistant lubrication engineer until 1940 when he entered the army as a second lieutenant. He was in service until 1946, emerging with the rank of lieutenant-colonel, Signal Corps. Mr. Berryman joined Air Reduction in 1946 and served in the technical sales division as machine welding specialist and assistant metallurgical engineer until his promotion.

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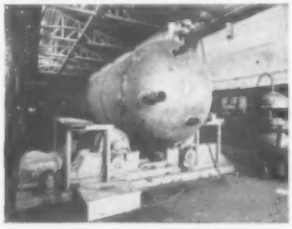
REED *ENGINEERED* **TURNING ROLLS**

THE ONLY COMPLETE LINE OF MODERN TANK WELDING EQUIPMENT

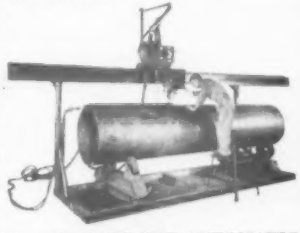
★ **THE NEW RD-20 TURNING ROLL**

Cap. 2,000 lbs.—handles up to 8 ft. × 12 ft. tanks. Priced at $650.00 F.O.B. Factory. Described in Bulletin No. 70.



★ **HEAVY DUTY TURNING ROLLS**

Built in 5 standard sizes—2 ton, 6 ton, 12½ ton, 25 ton and 50 ton. Complete details shown in Bulletin No. 68.



★ **UNIT TYPE FOR AUTOMATIC WELDING**

Combines Turning Rolls & Track Support into one compact unit. Made in 5 standard sizes—Special units made to order.

★ **POWER DRIVEN PIPE ROLLS**

For accurate fit-up, assembly & welding. Both standard & special units built to your requirements.

We Build a Complete Line of Tank Welding Equipment Including Bending Rolls, Assembly Presses, Horn Jigs, Track Support & Welding Gantries.

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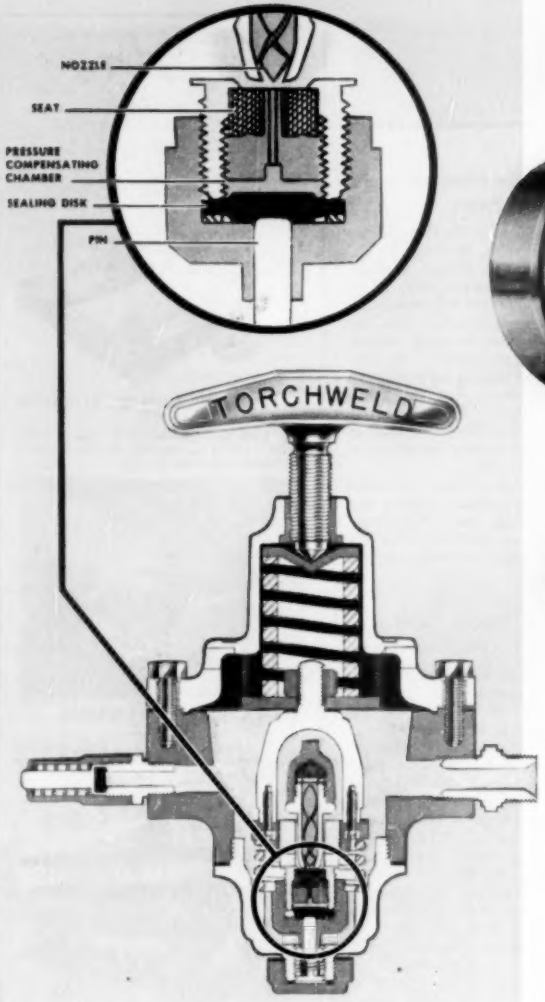
CARTHAGE, MISSOURI, U.S.A.

Biggest News



Here's why Torchweld "6500" delivers constant pressure and volume regardless of cylinder pressure

In any regulator the pressure of the incoming gas is one of the forces operating the valve mechanism. As cylinder pressure drops, this force decreases, causing a variation in the volume of gas flowing through the valve.

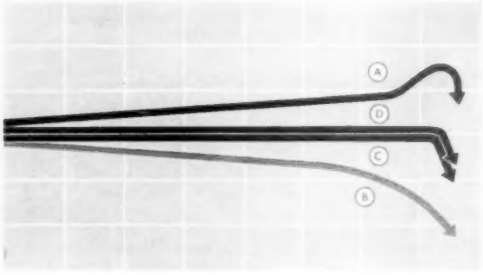
In the TORCHWELD "6500", a pressure compensating chamber below the seat counteracts the effect of this decreasing force.

A small passage in the valve seat permits gas *at cylinder pressure* to enter the chamber. At the bottom of the chamber is a reinforced rubber sealing disk. Below the disk is a pin which rests against the back of the regulator.

The forces within the chamber act upon the disk and pin so that there is a resultant effective force which tends to move the seat upward toward the nozzle.

As cylinder pressure drops this upward force diminishes, resulting in a gradual increase of the spacing between seat and nozzle. This compensates for the effects of decreasing cylinder pressures, and thus maintains constant delivery pressure and volume.

Here's how various types of regulators act as cylinder pressure drops



TYPE A—*Stem-type* single-stage regulator delivers at *increasingly higher* pressures as the cylinder empties. Frequent pressure adjustments are necessary.

TYPE B—*Nozzle-type* single-stage regulator delivers gas at pressures that *drop lower and lower* as the cylinder empties. Frequent pressure adjustments are necessary.

TYPE C—*Two-Stage* regulator gives uniform working pressure regardless of cylinder pressure, depending upon quality of regulator. Pressure adjustments are avoided.

TYPE D—TORCHWELD "6500" REGULATOR delivers constant working pressure (whatever it's set for) regardless of drop in cylinder pressure. No adjustments are necessary while welding or cutting.

in Regulators in 20 Years!

THE NEW

TORCHWELD "6500"

REGULATOR WITH PRESSURE COMPENSATING CHAMBER

NOW...the precise pressure control of the two-stage regulator for single-stage regulator cost...

Until now, whenever you bought a regulator you had to make a choice between two types—a single-stage regulator or a two-stage regulator—each with characteristic advantages.

Now, thanks to NCG research and design, you can get a regulator that combines the *best features* of *both* types, and the disadvantages of neither. The new, unique TORCHWELD "6500" offers you precise and *constant* delivery pressure and volume (at whatever setting you choose) *regardless of drop in cylinder pressure.*

Heretofore this time-saving characteristic could be had only in higher-priced two-stage regulators. Now, in the TORCHWELD "6500" it may be had for a price only slightly more than the average single-stage regulator—and you get, *in addition*, the *economy advantages* of a single-stage regulator.

It's all due to the NCG-engineered "*pressure compensating chamber*"—an exclusive, patented TORCHWELD feature that marks the first major advance in regulator design in 20 years. Further, all other features typical of TORCHWELD quality are retained—extra rugged construction, big streamlined gas passages for ample volume, the exclusive "SPIREX" nozzle element that prevents seat ignition, inlet filter, relief valve and few working parts to wear or repair.

Yes, the TORCHWELD "6500" is the greatest regulator value ever offered. Write for Illustrated Bulletin No. NTW-104 containing full details.

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Executive Offices:
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Please send me a copy of Bulletin NTW-104 containing full particulars on the sensational new TORCHWELD "6500" regulator.

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NEW LITERATURE

Cutting Production Cost with Electronic Controls

Cutting Production Costs with Electronic Controls contains 45 case studies describing actual examples of cost-saving production techniques. This book includes no catalog information. Its 65 pages are filled with facts showing how photoelectric and electronic controls solve problems and prevent bottlenecks in industry.

Each of these case studies describes an industrial control problem which has been solved through the use of electronics. The applications have been chosen from thousands of installations because of their general interest, and because each will suggest related uses in other fields.

To assist in quickly securing useful information, an index lists the applications both alphabetically and by industries. Free copies of this book are available from Photoswitch, Inc., 77 Broadway, Cambridge 42, Mass.

Electrode Catalog

The Champion Rivet Co. announces their new Welding Electrode Catalog. This 32-page illustrated catalog describes their full line of welding electrodes, including mild steel, low-alloy high-tensile, stainless steel, hard surfacing, tool and die, cast iron, bronze and aluminum as well as copper alloy and gas-welding rods. Copies available on request. Champion Rivet Co., E. 108th & Harvard Ave., Cleveland, Ohio.

1950 Directory of Eutectic Products

Latest metal-joining information on Eutectic "Low-Temperature Welding Alloys" is now available to all welders in the *Directory Welder for 1950*.

Featuring 65 outstanding EutecRods for torch welding and EutecTrodes for arc welding, this issue is profusely illustrated with case histories that will be a source of interest to welding engineers and technicians throughout leading industries.

Among the products listed in this preview of advance 1950 information is the announcement of the new line for stainless steel arc welding, which is outstanding for highest quality welds at lowest amperages without damage to base metal. These electrodes are known as Eutec-Staintrodes and are available for all types of low-heat stainless steel welding, depending upon composition of base metal. An unusual item in this new line is Eutec-Stainrod A for gas welding only, which is flux coated to insure perfect welds at lowest heat.

A complete Selection Chart is also included for information on the numerous specialized welding alloys of Eutectic for particular jobs.

For your copy of *Directory Welder for 1950*, write to Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

Flame Cutting

Electric-Eye Flame Cutting—New bulletin published by Joseph T. Ryerson & Son, Inc., steel distributors, illustrates intricate and unusual steel shapes supplied by this firm, cut to customer's order with their new Electric-Eye flame-cutting equipment. Typical of some of the irregular shapes furnished are Diesel locomotive parts, sprockets, grinding wheels, boom bars, crankshafts, machine and equipment frames and ornamental pieces. Shapes cut with the Electric-Eye machine are said to have sharper, squarer corners and greater accuracy than can be cut with other mechanized flame cutters, resulting in savings in fabricating costs and opening up new opportunities to use parts made of rolled steel. For copy of this bulletin address Joseph T. Ryerson & Son, Inc., at their nearest plant: Chicago, Milwaukee, Detroit, St. Louis, Cincinnati, Cleveland, Pittsburgh, Philadelphia, Buffalo, New York, Boston, Los Angeles, San Francisco.

Restoring Fits with Metallizing

The November issue of the *Metco News* reports that users of metallizing have found rebuilding fits of all kinds a great money and time saver. For instance, a large bus company reports real money-saving on motor blower end plates on its G.M.C. Diesel bus engines. The part, of cast aluminum, contains two ball-bearing housings—2.0475 in. diameter x 1 in. deep. In operation, the press fit is often lost and must be restored. Cost of a new plate is $20. With metallizing, the entire operation—including preparation, spraying and finishing takes less than an hour. They rebuild an average of 12 end-plates a week at a cost of $1.35 each. Savings—about $18.50 an end plate—close to $225 per week or $11,700 per year. That's not all, some of these metallized end plates have been in service 5 years and are still good. New plates last about a year—the metallized surfaces have already outlasted new ones 5 to 1.

Another user tells of rebuilding a 30-in. spindle with three different bearing race diameters—3.25, 3.625 and 3.875 in. The surfaces were sprayed with 0.10 carbon steel, 0.030 in. on a side, and machine finished. Here is the pay off—new spindles cost $110—total cost of the metallizing job was $2.75 or about 3% of the cost of a new spindle.

Many other applications are also suggested such as axle shafts, brake drums, cylinder liners, glands sections, plungers, lathe beds, etc. Write for your copy of the *Metco News*, Vol. 4, No. 11. Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

Welding Catalog

Special Welding Alloy Co., Inc., 27–33 Jackson Ave., Long Island City 1, N. Y., has issued an attractive pocket-size catalog describing their gas-welding apparatus, low-temperature rods, gas-welding and brazing rods, P & H arc welders and electrodes. Technical information for the welder also included. Copy available on request.

Weld Coating Materials

The Texas Alloy Products Co., 2110 Quitman St., Houston 10, Tex., has issued a new catalog which provides information on their activities as processors in problems involving alloyed metals in heat, corrosion, or abrasion.

These functions involve the selection, treatment and processing of alloys for these purposes, which fall in three general groups: (1) solid alloys as produced, or with heat treatment; (2) solid alloys case treated; (3) weld coatings with, or without heat treatment.

The Company has recently completed classification of weld-coating materials, charts for which are presented in this booklet. Copy available on request.

Safety Catalog Available

Willson Products, Inc., Reading, Pa., has just issued their new industrial safety equipment catalog. In addition to providing product information on the company's line of eye and respiratory equipment, this 64-page book contains a fund of technical and reference material. This has been included to help the user select the proper type and style of equipment for the specific occupational hazard involved, and to give him information on its use and care.

Among the subjects discussed are: (1) digest of U. S. Federal Specifications for heat-treated glass, and tests made to insure conformance and performance; (2) discussion of the advantages and proper use of plastics as applied to the safety field; (3) types of filter glass available for use in occupations where varying degrees of glare and radiant energy are encountered; (4) discussion of types of respiratory hazards, what respirators to use for specific hazards, and care and maintenance of respirators; (5) gas mask selector tables showing gases and vapors prevalent in industry, with suggestions on gas mask and canister assemblies recommended for specific contaminants.

Charts throughout the catalog show at a glance the comparative features of various styles and aid in the selection of the most comfortable style for the user. The block is profusely illustrated.

Material Handling

This 16-page booklet "Material Handling," shows how proper "positioning" of materials saves unnecessary handlings during production operations.

It contains illustrations and descriptions of 12 different types of equipment of various manufacturers for positioning. These point out many proved ways of positioning materials.

The emphasis in the past by industrial executives has been on transportation and tiering of materials. The third phase of material handling—positioning of materials—has been very much neglected, particularly in production processes.

This booklet was written by George G. Raymond, President and Treasurer, and William C. House, Vice-President of Lyon-Raymond Corp.

Copies of this booklet "Material Handling" may be obtained direct from Lyon-Raymond Corp., 23662 Madison St., Greene, N. Y.

Steel Castings Chart

Factual engineering data emphasizing the versatility, strength and dependability of steel castings is incorporated in a comprehensive technical chart now being distributed by the Steel Founders' Society of America as an aid to design engineers and purchasing Department Engineering staffs.

Compiled in connection with the Society's extensive research and product development program, the chart is intended to serve as a reliable reference guide to economical production of steel castings. It comprises a simplified tabular listing of virtually all general engineering types of steel castings, classified according to tensile strengths. Essential data include indicated engineering and design applications, current specifications and typical specifications for especial tensile grade requirements. Also included are ready-reference data on specific yield point, elongation, reduction of area, hardness and impact evaluations, endurance limits, modulus of elasticity, machinability and types of heat treatments.

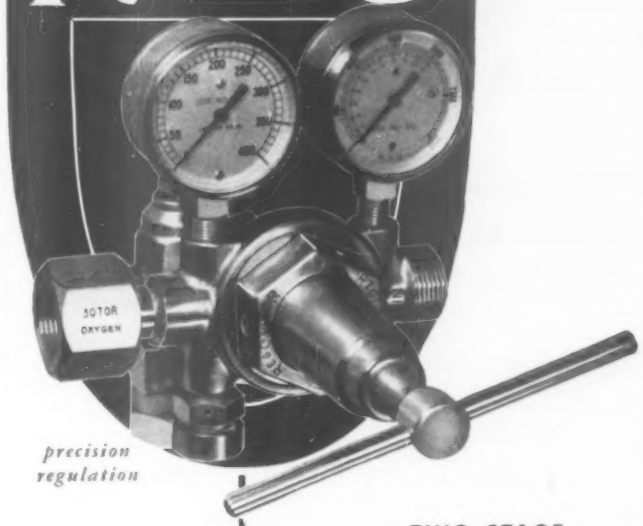
Although prepared primarily for the convenience of design and product development engineers, the chart is also being made available to management executives, editors, educators, students and others interested in engineering design and redesign for cost reduction.

Copies may be obtained from F. Kermit Donaldson, Executive Vice-President, Steel Founders' Society of America, 920 Midland Bldg., Cleveland 15, Ohio.

Safety Goggles

A new booklet entitled "How to Set Up and Conduct a Safety Rx Program," containing information useful to any concern planning to establish or expand a program of eye safety through the use of prescription safety goggles has been prepared by American Optical Co., Southbridge, Mass.

REGO*



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TWO-STAGE

REGOLATOR

The precision performance of the two-stage RegOlator is especially desirable for piped distribution systems and other applications where large volumes of high pressure gases must be controlled accurately.

Two-Stage RegOlator Gives You Plus Performance!

Constant delivery pressure regardless of drop in pressure at the inlet . . . Patented design incorporates nozzle-type first stage counterbalanced by stem-type second stage . . . Triple action cartridge filter eliminates troubles usually caused by rust, dust or dirt.

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The BASTIAN-BLESSING Co.

4201 Peterson Ave. Chicago 30, Ill.

Pioneer and Leader in the Design and Manufacture of Precision Equipment for Using and Controlling High Pressure Gases

FOR STAINLESS AND LOW ALLOY WELDING HELP

Consult Your Arcos Distributor

- **QUICK SERVICE** - From ample local distributor stocks.
- **ELECTRODE SELECTION** - Experienced distributor help on proper selection from 56 different grades.
- **UNUSUAL PROBLEMS** - Distributor can call on Arcos Field Engineer.

ARCOS DISTRIBUTORS

NEW ENGLAND

Hartford 6, Conn. — Arcos Corporation
Boston, Mass. — Arcos Corporation

MIDDLE ATLANTIC

Buffalo, N. Y. — Root, Neal & Co.
Erie, Penna. — Boyd Welding Co.
New York, N. Y. — Arcos Corp., Phila., Pa.
New Jersey — Arcos Corp., Phila., Pa.
Philadelphia, Pa. — Arcos Corporation
Pittsburgh, Pa. — Williams & Co., Inc.
Rochester, N. Y. — Rochester Welding Supply Co.

MIDDLE WEST

Chicago, Ill. — Machinery & Welder Corp.
Cincinnati, Ohio — Williams & Co., Inc.
Cleveland, Ohio — Williams & Co., Inc.
Columbus, Ohio — Williams & Co., Inc.
Denver, Colo. — Western Oxygen Company, Inc.
Detroit, Mich. — C. E. Phillips & Company, Inc.
Fort Wayne, Indiana — Sutton-Garten Company
Indianapolis, Ind. — Sutton-Garten Company
Kansas City, Mo. — Hohenschild Welders Supply Co.
Milwaukee, Wis. — Machinery & Welder Corp.
Minneapolis, Minn. — Machinery & Welder Corp.
Moline, Ill. — Machinery & Welder Corp.
St. Louis, Mo. — Machinery & Welder Corp.
Salt Lake City, Utah — Whitmore Oxygen Co.
Toledo, Ohio — Williams & Company, Inc.

SOUTH and SOUTHWEST

Albuquerque, N. Mex. — Industrial Supply Co.
Atlanta, Ga. — J. M. Tull Metal & Supply Co., Inc.
Borger, Texas — Hart Industrial Supply Co.
Houston, Texas — Champion Industrial Sales Co.
Kingsport, Tenn. — Slip-Not Belting Corp.
Oklahoma City, Okla. — Hart Industrial Supply Co.
Pampa, Texas — Hart Industrial Supply Co.
Phoenix, Ariz. — Arizona Welding Equipment Co.
Tucson, Ariz. — Arizona Welding Equipment Co.
Tulsa, Oklahoma — Krisman Industrial Supply Co.

WEST COAST

Bakersfield, Calif. — Victor Equipment Company
Fresno, Calif. — Victor Equipment Company
Los Angeles, Calif. — Victor Equipment Company
Portland, Ore. — J. E. Haseltine & Company
San Diego, Calif. — Victor Equipment Company
San Francisco, Calif. — Victor Equipment Company
Seattle, Wash. — J. E. Haseltine & Company
Spokane, Wash. — J. E. Haseltine & Company

FOREIGN

Hilo, Hawaii — Hawaiian Gas Products, Ltd.
Honolulu, Hawaii — Hawaiian Gas Products, Ltd.
Toronto, Canada — Alloy Metal Sales, Ltd.

ARCOS CORPORATION

1500 South 50th Street, Philadelphia 43, Pa.

FIELD ENGINEERING OFFICES: Chicago, Ill., Los Angeles, Calif., Pittsburgh, Penna.

The booklet includes suggestions on how to obtain the necessary professional services to implement an eye safety program and step-by-step instructions on the use of a new Safety Rx Order Book supplied by the company to industrial concerns.

Information in the booklet is based largely on existing practices in some of the country's largest and safest industrial plants—users of American Optical Co.'s "Corrective-Protective" service.

Copies of the booklet may be obtained upon request.

Hard Surfacing

Alloy Rods Co., York, Pa., has issued a new illustrated 4-page pamphlet describing their new electrode—Chrome-Boride—for unusual hard-surfacing applications, a new contribution to prolonging the life of expensive equipment and lowering the cost of maintaining it. One of the hardest and most abrasive resistant substances known is the combination of chromium and boron (Chrome-Boride). High cost of production and application has hitherto limited its use. After intensive research the Alloy Rods Co. developed the Chrome-Boride electrode which utilizes the terrific heat of the welding arc over (6000 ° F.) to produce this alloy cheaply and in a form that makes application easy. The overall hardness of the weld deposit is 68 to 72 Rockwell "C" as air cooled from welding in the second or succeeding layers. With this extreme hardness the weld metal does not respond to heat treatment nor can it be machined. If finishing is required it can be obtained by grinding. Typical applications are: crusher rools and jaws, scarifier teeth, dipper teeth, dipper buckets, bucket lips, drill bits, earth-moving equipment, dredging and mining equipment.

Heat-Resisting Castings

Chicago Steel Foundry Co., Kedzie Ave. at 37th St., Chicago 32, Ill., announces a 20-page booklet describing Pyrasteel heat-resisting alloys. Technical data including welding information included.

Weld Brazing

Uniworld Research Corporation of America, 1302 Ontario St., Cleveland 13, Ohio, in a 4-page pamphlet announce "Weldbrazing" method using steel filler alloys instead of the nonferrous alloys operating at a temperature of 1950° F.

Welded Overlaps

Reprints are available of an article entitled "New Shoes Not Needed." This deals with the use of welded overlays for salvage and reduction of future wear on locomotive roller bearing shoes. Copies are gratis. Ampco Metal, Inc., Milwaukee 15, Wis.

FOR GOOD SERVICE IN GOOD CONNECTIONS

Get acquainted with the well-stocked Tube-Turn distributor in your locality

TUBE-TURN

WELDING FITTINGS AND FLANGES

He handles the firmly established, quality brand of welding fittings and flanges. He handles a wide range of types and sizes. He carries a big stock. He knows piping. He is close at hand. For his address, write, wire, or phone your nearest Tube Turns' district office.

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Chicago: 600 South Michigan Avenue, Harrison 7-8527
Houston: 1704 Commerce Building, Charter 1668
Los Angeles: 447 General Petroleum Building, Madison 6-3219
New York: 150 Broadway, Rector 2-7844
Philadelphia: Broad Street Station Building, Rittenhouse 6-0722
Pittsburgh: 3001 Grant Building, Atlantic 1-8848
San Francisco: 2611 Russ Building, Garfield 1-2594
Tulsa: 317 South Detroit Avenue, Telephone 2-9193

TUBE-TURN SEAMLESS WELDING FITTINGS — RANGE OF SIZES

DESCRIPTION	STANDARD WEIGHT	EXTRA STRONG	SCHEDULE 160	DOUBLE EXTRA STRONG	LIGHT GAUGE	
					NOMINAL PIPE SIZE	IRON PIPE SIZE
ELBOWS—90° Long Radius	½"-24"	½"-24"	1"-12"	½"-8"	4"-24"	½"-12"
ELBOWS—90° Short Radius	1"-30"	1½"-30"				
ELBOWS—45° Long Radius	½"-30"	½"-30"	1"-12"	½"-8"	4"-24"	½"-12"
RETURNS—180° Long Radius	½"-24"	½"-24"	1"-12"	2"-8"	4"-24"	½"-12"
RETURNS—180° Short Radius	1"-30"	1½"-30"				
RETURNS—180° Extra Long Radius	1"-2½"*	1"-2½"*				
TEES—Straight	½"-24"	½"-24"	1"-12"	½"-8"		
TEES—Reducing Outlet	½"-24"	½"-24"	½"-12"	½"-8"		
REDUCERS—Concentric and Eccentric	¾"x½" thru 24"x20"	¾"x½" thru 24"x20"	¾"x½" thru 12"x10"	¾"x½" thru 8"x6"		
CAPS	½"-24"	½"-24"	1"-12"	1"-8"		
STUB ENDS—Lap Joint	½"-24"	½"-24"				
SADDLES	2"-24"**					
LATERALS—Straight	1"-24"	1"-24"				
LATERALS—Reducing on run	1"-24"	1"-24"				
CROSSES—Straight and Reducing	½"-24"	½"-24"				
RINGS—Welding, Groove Type	½"-24"	1"-24"		1½"-8"		
RINGS—Welding, Ridge Type	½"-12"	½"-12"				
SLEEVES—Welding	2"-24"**					

** Since saddles and sleeves are for external reinforcement only, they do not conform to iron pipe size thicknesses.

TUBE-TURN FORGED STEEL FLANGES — RANGE OF SIZES

DESCRIPTION	150 LB.	300 LB.	400 LB.	600 LB.	900 LB.	1500 LB.	2500 LB.
WELDING NECK	½"-24"	½"-24"	½"-24"†	½"-24"	½"-24"†	½"-24"	½"-12"
SLIP-ON	½"-24"	½"-24"	½"-24"†	½"-24"	½"-24"†	½"-24"	½"-12"
LAP JOINT	½"-24"	½"-24"	½"-24"†	½"-24"	½"-24"†	½"-24"	½"-12"
THREADED	½"-24"	½"-24"	½"-24"†	½"-24"	½"-24"†	½"-12"	½"-12"
BLIND	½"-24"	½"-24"	½"-24"†	½"-24"	½"-24"†	½"-24"	½"-12"
SOCKET TYPE	¼"-24"	¼"-4"	¼"-2½"†	¼"-2½"			
REDUCING—Threaded or Slip-On	¾"-24"	¾"-24"	¾"-24"†	¾"-24"	¾"-24"†	¾"-12"	¾"-12"
ORIFICE—Threaded		8"-24"	4"-12"	4"-12"	3"-12"	3"-12"	
ORIFICE—Slip-On		8"-24"					
ORIFICE—Welding Neck		8"-24"	4"-12"	3"-12"	3"-12"	3"-12"	

† Dimensions on class thru 2½" same as for 600 lb. flanges.
* Dimensions on class thru 2½" same as for 1500 lb. flanges.

In addition to carbon steel welding fittings and flanges listed here, the complete Tube-Turn line embraces many other metals and alloys—types 304, 347, and 316 stainless steel, carbon moly and chrome moly steels, copper, aluminum, brass, Monel Metal, Inconel, nickel, wrought iron. Ask your Tube-Turn distributor for catalogs and other reference material.

NEW PRODUCTS

Miller's New Products

At the National Metal Exposition in Cleveland, Ohio, the Miller Electric Mfg. Co., of Appleton, Wis., featured in operation several welders.

The Miller lightweight portable spot welder for stainless and mild steel up to 1/8 in. combines thickness and incorporates a new toggle-action tong lever for greatly increased tong pressure with a minimum of exertion on the lever itself.

Adjacent to the small 3-kva. spot welder was Miller's 10-kva. portable model. This unit was suspended in production fashion from a counterweighted overhead boom and the Welder itself was mounted in a new type bail enabling the welder to reach into hard-to-get-at corners with a minimum of effort on the part of the operator.

An outstanding feature of this display was a completely portable "Heliarc" unit. The unit was mounted on Miller's rubber-tired truck and consisted of the a.-c. welder for "Hiliarc" welding, a timer control making the welder suitable for "Heliarc" spot welding, a water coolant system and mounted with the argon tank on the truck. The unit as such is completely portable and requires only outside connection to 220-v., single-phase power service. The unit as shown can be used for metallic arc welding, for "Heliarc" welding and for "Heliarc" spot welding. The Linde Air Products Co.'s spot-welding torch or "poke gun," as it is popularly called, was hooked up to this welder in actual operation.

Solder Alloy for Bonding Aluminum and Ferrous and Nonferrous Metals

A new hard solder-type alloy for joining aluminum to steel, bronze and copper as well as aluminum, is announced by Eutectic Welding Alloys Corp., New York.

Of interest to manufacturers of electrical aluminum units, delicate or thin gage parts, this new low melting, high-strength alloy is known as EutecRod 192. Available in 1/16", 3/32" and 1/8" in. coil form, it is recommended for sealing cracks, spot welds and general soldering of aluminum. It is especially useful where a solder as white as possible is desired.

Many instrument makers, especially of aircraft instruments, requiring a thin flowing solder, will find EutecRod 192 extremely desirable. EutecRod 192 is desirable also for electronic and television work, where heat lower than ordinary silvers is required. Yet where higher strength and remelt temperature than soft solders are specified, EutecRod 192 is again outstanding. It gives the highest strength bond ever obtained between aluminum and ferrous and nonferrous metals and all alloys tested in 20 years of Eutectic research in this field.

Bonding temperature of EutecRod 192 is 650–700° F., with a tensile strength of 11,000 psi. and with good corrosion resistance and excellent electrical conductivity. It is used with Eutector Flux 192, which acts as a temperature indicator. When the flux begins to smoke, the alloy is applied and spreads out rapidly throughout the entire joint. A clean, smooth weld without damage to base metal results.

Aluminum Brazing Wire

Air Reduction, manufacturer of industrial gases and welding equipment, has announced that No. 718 aluminum brazing wire replaces No. 716.

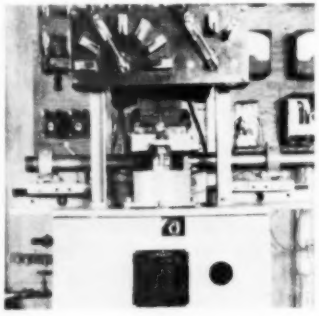
According to Airco, joints made with No. 718 wire are more resistant to corrosion, and parts required to withstand pressure show fewer leaks than with the wire formerly sold.

The No. 718 aluminum brazing wire is sold in 3/32 and 1/8 in. diameters and is immediately available. The standard package for each coil is approximately 55 lb.

Airco recommends that Elite Aluminum Brazing Flux be used in conjunction with the new wire.

Electric Tube Welder

An electric tube welder has been developed by J. B. Borgadt, 2036 E. 86th St., Cleveland 6, Ohio, and it introduces a new type of electrode, surface-contact to convey the current across the seam cleft in preformed tubing to fuse the metal, and many other new improvements. Several advantages are claimed, an electric resistance weld that may be a flash weld, butt weld or modification thereof, as may be desired. The weld, in most cases, is a fine grain equal, or better than the parent metal. Free from transient zone, discoloration adjacent to the weld, recurrent welds and inclusions, with small flash and up-set requiring little finishing to produce acceptable tubing.



Welding current, weld time and pressure may be combined and synchronized accurately in producing a tube weld that conforms to correct metallurgical principles and fulfills all requirements of good resistance welds. Tubing of a number of materials has been welded with excellent results.

Carbon steel up to 1045, low-alloy steel, alloy steel such as 4130, and stainless steel, ordinary skelp, also has given excellent results.

Spot Welder Stand

A new lightweight steel stand designed to further increase the versatility of its recently marketed portable and self-operating spot welder is now being introduced for the first time by Greyhound A.-C. Arc Welder Corp., 606 Johnson Ave., Brooklyn 6, N. Y., it was announced recently.

When mounted on the stand, foot-lever operation frees the operators' hands, and the Greyhound portable spot-welder becomes an easy to use and efficient stationary model, according to the manufacturer. The unit can again be used as a portable device by simply removing the two metal brackets holding the portable spot welder to the stand.

Company executives report that the new stand is the result of many requests from industrial plants for a sturdy 110 or 220 v. portable spot welder which could also be used as a stationary model whenever the need arises.

Nickel-Silver Brazing Rod

All State Welding Alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y., recently announced a new flux-coated nickel-silver brazing rod for application with the oxy-acetylene blowpipe.

This new rod is well described as all-purpose or general utility. Field tests on 14 different metals have indicated its selection wherever bronze rod is normally considered. It brazes with higher strength (tensile above 85,000 psi., shear above 160,000 psi.), and full machinability with less alloy.

Superior performance has been demon-

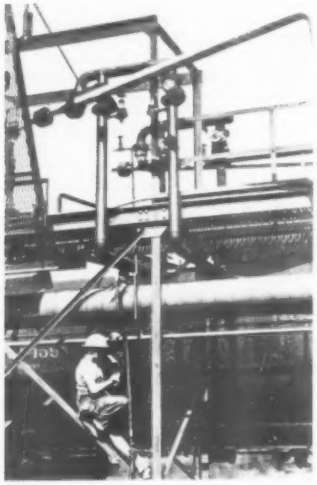
strated on steel, stainless steel, copper, copper nickel and nickel.

There is no fuming and no glare as this new rod is used. The flux actually bends to the rod and will not flake off. The rod will not bare itself by excessive charring of the coating.

Coated Nickel-Silver brazing rod is being made available through All-State distributors.

All-Aluminum Swing Line Facilitates Loading of Tank Cars

Recently, at the Ohio Oil Co.'s 30,000 bbl. per day refinery near Robinson, Ill., the filling of tank cars has been expedited and worker fatigue lessened by the use of a newly designed all-aluminum swing line. It is 12 ft. in length, 4 in. in diameter, fabricated with Tube-Turn aluminum welding fittings manufactured by Tube Turns, Inc., Louisville, Ky. After being fabricated the line was counter weighted. The discharge end of the line is equipped with a Tube-Turn tee, so that the oil is directed to both ends of the tank, adding considerably to filling efficiency.



All-aluminum swing line

Weight of the all-aluminum assembly is approximately 42 lb. Had it been fabricated in the conventional way, with carbon-steel pipe and fittings, it would weigh approximately 129 lb. And it would require correspondingly greater physical effort to maneuver.

The aluminum pipe and Tube-Turn aluminum fittings used in the new swing line are of 38-F alloy. The shop-fabricated joints were welded by the argon gas-shielded tungsten arc method.

The accompanying photograph of a section of the loading rack shows (1) the main bridge, (2) a counter-weighted catwalk, which is lowered to the car and gives the operator quick access to the lidded dome and (3) the swing line, which is so easily positioned.

Distilling Column

Distilling Column

Arco-Atlantic Corp., of Philadelphia, used arc welding in the fabrication of this 94-ft 5-in. distilling column. The base tapers from 6 ft in diameter to meet the $2^{1}/_{2}$-ft diameter of the straight shell. The base and two bottom sections of the shell are $^{3}/_{8}$-in. thick, while the four top sections are $^{5}/_{16}$-in. thick. The column is equipped with 32 tray plates. Each tray is accessible through a 16- x 20-in. manhole. This unfired pressure vessel, constructed according to A.S.M.E. code, is completely welded except for the bolts mounting the manhole covers. The ladder, welded to the column, and the framework supporting the column in the freight car are both made of mild steel and fabricated by welding.

Photo and data, courtesy General Electric Co.

Complete Remote Control for D.-C. Arc-Welding Machines

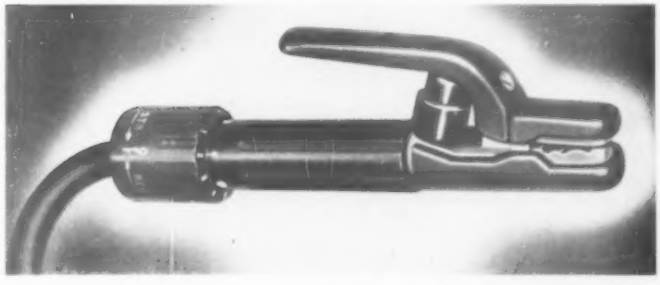
Shown herewith are photographs of a new attachment for A.-C. driven, D.-C. arc-welding machines known as "Remote Control for D.-C. Welders." Developed and patented by the Foster Transformer Co., Cincinnati, Ohio, the device transfers all of the machine controls to the electrode holder. It consists of two parts: the control box, housed in stainless steel which mounts on the welding machine, and a standard holder equipped with a special grip. With the device it is possible not only to start and stop the welding machine and select polarity, but to regulate the heat as well, right at the holder.

Connection is made between the holder controls and the control box by means of three No. 20 wires rope-spiraled in the cable, along with the work cable. A special inexpensive connector is provided to splice in additional lengths of cable. The cable will sell for about the same price as regular cable. Complete instructions are furnished, and the average electrician or maintenance man can install the device in an hour or less.

The holder proper is a standard popular make and is replaceable. Two control knobs are located at the back of the holder grip concentric with the cable. One of these actuates a double throw switch. Depending upon which direction the switch is turned from the off position, the machine is started with either straight or reversed polarity. The other knob is calibrated for reference and adjusts the heat with smooth stepless control. The holder and grip weighs only 3 oz. more than the regular holder, and the replacement cost of the grip will be nominal. Since the device operates electrically, there are no moving parts other than the knobs on the handle and relays in the control box.

For straight polarity down-hand welding, the control covers almost the entire heat range, with one setting of the machine from maximum down. For reverse polarity requirements, the machine is set for the largest electrode size, with the machine voltage control full on. The control will then cover not only the rod size selected, but the next two smaller rod sizes as well.

Jobbers are now being appointed for the control and it will be ready for distribution early in December. At present the equipment is available for Lincoln 200- and 400-amp. machines (Model L 240), Lincoln 300-amp. machines (Model L 300) and Hobart 300-amp. machines (Model H 300). Early in 1950 it will be available for all popular makes and sizes, including gas-driven equipment.



Remote control for D.-C. welders

Air Reduction Announces "Flamecraft" Oxyacetylene Outfit

Air Reduction, manufacturers of industrial gases and welding equipment, have announced the availability of the "Flamecraft" oxyacetylene welding and cutting outfit. This unit will be marketed as a "package," including oxygen and acetylene cylinders, welding torch, cutting attachment, tips, regulators, hose, goggles, cylinder truck, fluxes, an assortment of welding and hardfacing rods and an instruction folder on the proper handling and operation of the equipment.

The cylinders are the 60-ft. acetylene and the 122-ft. oxygen which were announced recently. They are supplied with the Flame craft outfit on a lease basis for a 25-yr. period, the estimated lifetime of the cylinders. Under the lease arrangement, demurrage charges are eliminated and maintenance of the cylinders guaranteed.

Airco believes the Flamecraft outfit will make welding and cutting attractive to a whole new field of small-quantity users, such as garages, farms, small shops and individuals.

The Flamecraft outfit lists for $166.87, less gas, and may be purchased through any of the more than 800 authorized Airco dealers throughout the country.

Longest Steelweld Shear

The longest Steelweld Shear built to date has just been completed by The Cleveland Crane & Engineering Co., Wickliffe, Ohio.

The machine has a shearing capacity of 18 ft. of $^3/_{16}$-in. mild steel at 50 strokes per minute. Like all Steelweld Shears it operates on the pivoted-blade principle. The blade travels in a circular path without the use of customary guides and slides common with guillotine-type shears. Thus, difficulties from wear at these points are eliminated.

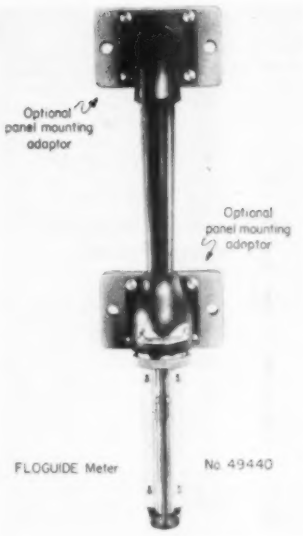
Ball-bearing transfers are provided in the bed, facilitating movement of steel through the knives. A motor-operated back gage with slow and fast control buttons located conveniently at middle front of machine makes it easy to accurately position material to be cut. Because the back gage indicator is readily seen through the oblong slot in the hold-down beam, there is no need for the operator to walk to end or rear of shear to adjust the gage and many time-consuming steps are thereby saved. This indicator reads in inches and $^1/_{64}$ths.

The shearing action is controlled by an electrically operated foot switch which can be moved about the floor to the convenience of the operator. The foot switch substitutes tireless toe action for tiresome knee action required by the conventional foot treadle which is ordinarily used to operate the clutch through mechanical means.

Frame and blade are of all-welded steel, one-piece construction with the heavy bed extending below the floor. The bed and crown are welded to the end housings, thus forming an integral unit having great strength. This construction assures minimum deflection and long-time accuracy.

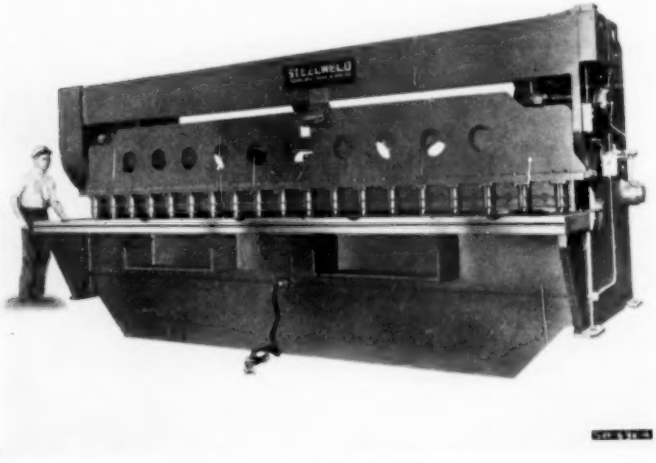
Gas Flowmeter

A new variable-area gas flowmeter known as the "Floguide" has been developed by the Fischer & Porter Co. The tapered precision-bore metering tube and the "float" are fabricated from stainless steel. The metering tube is brazed to the cast-iron inlet and outlet fittings, permitting simple and attractive panel installations. The extension below the metering tube carries an accurate metering scale, and an indicator below the float permits direct reading of flow rate. The wide-angle scale can be read from within a 180° arc and is also rotatable for complete flexibility of installation.



The Floguide is available in capacities ranging from 45 to 16,000 standard cu. ft. of carbon dioxide per hour, 200 to 76,000 standard cu. ft per hour of hydrogen and comparable capacities for other gases. Although primarily designed for low-pressure service, floguide meters can be furnished to withstand 600 psig. working pressure in all sizes. Maximum operating temperature is limited by the properties of commercially available packings.

Complete information can be obtained from the Fischer & Porter Co., County Line Rd., Hatboro, Pa.



Longest steelweld shear

No Slag Removal Electrode for Steel

Steel-Tectic, a new principle high-speed electrode which welds bead over bead without the need for removing slag, is now being marketed by Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

The $^3/_{32}$-in. Steel-Tectic electrode can be used at as low as 50 amp. on thin steel without danger of burning through, whereas conventional electrodes require 100 amp. and involve risks of burning through. This reduces distortion and is economical because it allows the use of heavier, less expensive rods. Yet for piecework production, Steel-Tectic can be run fast at high amperages, as a thin depositing electrode with a very short arc. Less experienced welders gain superior results because of the wide range of current and various arcs which can be used—as well as the all-position feature of the rod: vertical, horizontal or downhand.

A newly developed Eutectic FrigidArc flux coating is responsible for the unusual and different performance of this electrode. It forms a protective envelope around the weld area, permitting a spray deposit free of weakening oxides and inclusions. It is unnecessary for the welder to stop and brush or chip away the slag; he simply welds right over the previous pass, for a strong, high-quality weld. The elimination of chipping therefore constitutes a safety factor, since there is no danger to the welder's eyes.

Because of the various factors of high speed, less filler metal used and better quality of weld, the actual cost of foot-per-weld, with Steel-Tectic is lower than ordinary steel electrodes.

All-Welded Steel Section Adds 21,000 Seats to Michigan Stadium

To accommodate the loyal fans and the not so loyal rivals of its famous Wolverine football team, the University of Michigan at Ann Arbor, Mich., has the largest university-owned stadium in the world. To handle the increasingly larger football crowds, the original seating capacity of 76,000 was increased recently to 97,000 by the addition of an all-welded steel seating section on top of the present concrete stadium.

Steel plates, ½ in. thick, were formed into a single-step section and then shop welded into 4-step units. These 4-step units in turn were welded together in the stadium. Each preformed steel step section, approximately 15 ft. long, is welded with a solid continuous weld to the section immediately below as well as to the section adjacent to it. The welded step sections are supported by a welded steel substructure.

There was an estimated total of 12 miles of welding, 7 of which were performed in the field. All field welding was done with Lincoln welding machines and electrodes. The horizontal fillet welds and the flat butt welds between step sections were made with "Fleetweld No. 11." The vertical welds on the step risers of the step section were made with "Fleetweld No. 5."

Seat supports are welded to the step sections and wooden seat boards fastened to these supports to complete the all-welded stadium extension. The original concrete stadium and the welded extension were designed by the Osborn Co. of Cleveland. The steel was furnished, erected and welded by Whitehead and Kales of Detroit. General contractor was Henry de Koning Construction Co. of Ann Arbor.

Regulator

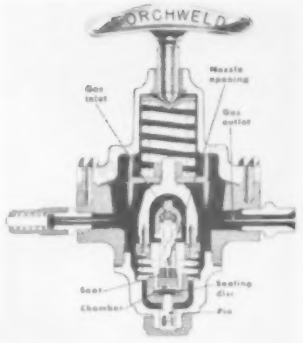
A new type of welding and cutting regulator which maintains constant volume and pressure of gas, without requiring two-stage reduction, is announced by the National Cylinder Gas Co., Chicago.

Its price is substantially less than the average price for two-stage regulators and only slightly more than the average for single-stage regulators. Maintenance cost is said to be low due to its simplified design and rugged construction.

The new regulator, known as the Torchweld "6500," incorporates a pressure compensating unit in the valve seat assembly which counteracts effects of decreasing cylinder pressure. Heretofore, according to N.C.G. engineers, only the two-stage regulator, with its relatively complex construction of two regulators in one body, has been able to maintain constant delivery pressure, despite the decrease in supply pressure which occurs as gas is withdrawn from a cylinder.

The pressure compensating unit in the Torchweld "6500" regulator consists of a small gas chamber below the valve seat, a reinforced-rubber sealing disk at the bottom of the chamber and a pin which rests between the disk and the back cap of the regulator.

Gas at cylinder pressure is admitted to the chamber, which is part of the movable seat assembly, through an orifice in the seat. The force of the gas in the chamber



results in an action which moves the seat gradually away from the nozzle as supply pressure decreases, permitting a constant rate of flow to be maintained.

Explanatory literature on the Torchweld "6500" may be obtained from N.C.G. branch offices, N.C.G. authorized dealers or by writing the National Cylinder Gas Co., 840 N. Michigan Ave., Chicago 11, Ill.

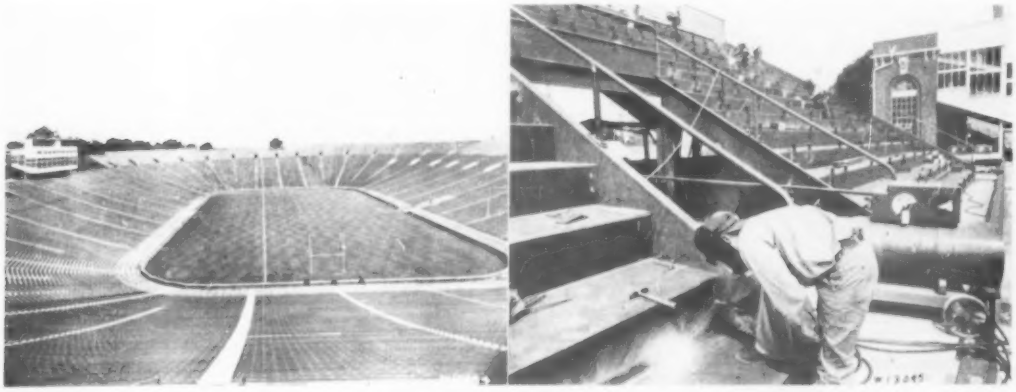
200-Amp. Machine-Driven Arc Welder

Air Reduction, manufacturers of industrial gases and welding equipment, have announced the latest addition to their line of arc welding machines, the 200-amp. Hornet "Special" arc welder.

This machine combines the compact 36A generator with a four-cylinder, 31-hp., air-cooled Wisconsin engine.

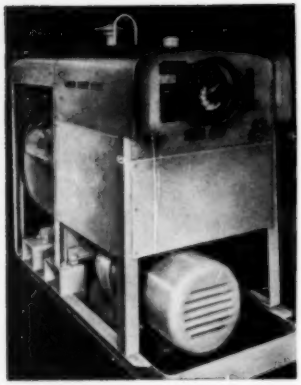
The 36A generator, which has a welding range from 40 amp. at 20 v. to 250 amp. at 40 v., features the following:

Efficient Operation: The 36A is built as a two-bearing unit. Closely spaced precision bearings provide maximum load safety. Double shields keep bearings dirt-free and hold grease in.



A welded steel addition around the top of the University of Michigan stadium at Ann Arbor, Mich., increases the seating capacity to 97,000, making this the world's largest university-owned stadium

Steel step sections, ½ in. thick and approximately 15 ft. long, are welded solidly and continuously to each other all the way around the stadium with an estimated 12 miles of welds



Simplified Current Control: The control wheel mounted on the panel shows accurate current markings—readily obtained by setting the pointer located in the center of the wheel. This hand wheel has five positions, with ample overlap to insure fine settings from minimum to maximum output of the machine. The need for meters is eliminated.

Self-Contained Exciter: The 36A is a self-excited generator with excitation of the main field supplied by an auxiliary brush. This insures instant recovery voltage over short circit.

The Hornet "Special" is 58½ in. long, 25⅝ in. wide, 47 in. high and weighs 825 lb. It comes equipped with a full-length drip-proof canopy. A lifting eye is provided on top.

Two-wheel, trailer-type running gear, with 4-ply pneumatic tires and a 38 in. long drawbar, is available as optional equipment. The Wilson Hornet "Special" is immediately available.

For further information, write Air Reduction, 60 E. 42nd St., New York 17, N. Y., or the Airco sales office nearest you.

Tempil° Pellets

Tempil° Corp. of 132 W. 22nd St., New York 11, N. Y., announces the development of additional high-temperature ratings of Tempil° Pellets to indicate 2100, 2200, 2300, 2400 and 2500° F.

Beginning with 113° F., Tempil° Pellets are now available in 12½° steps to 400° F., in 50° steps from 400 to 2000° F., and in 100° steps from 2000 to 2500° F.

Tempilstiks°, the crayon form of temperature indicator, are available in corresponding intervals from 113 to 2000° F.; while Tempilaq°, the paint form of temperature indicator, is available in similar steps from 113 to 1600° F. only.

abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,485,790—Method of Percussive Welding—Winfield J. Trott, Detroit, Mich., assignor to General Motors Corp., Detroit, Mich., a corporation of Delaware.

Trott's welding method involves the step of discharging a storage condenser that is connected to two members in spaced relation by causing one member to approach the other at an appreciable speed. The second member is lightly frictionally supported so that upon contact of the two members there will be maintained a substantially constant engaging force during the welding action.

2,486,092—Welding Electrode Holder—Bernardus Maria v. Amelsvoort, Eindhoven, Netherlands, assignor to Hartford National Bank & Trust Co., Hartford, Conn., as Trustee.

This electrode holder includes an insulating handle in which a supply electrode is housed. A welding electrode is positioned at an angle with respect to the insulating handle and an insulating mouthpiece surrounds the welding electrode. The mouthpiece is engaged with an aperture in a resilient clamping member carried by the insulating handle and the insulating mouthpiece may be manually adjusted toward or away from the insulating handle or be completely removed from the assembly without the use of a tool.

2,486,274—Welding Generator Safety Circuit—Harold J. Graham, Boston, Mass., assignor to Graham Mfg. Corp., Detroit, Mich., a corporation of Michigan.

The welding generator of this patent has an exciting circuit including a field winding for magnetizing the generator and a switching element for interrupting the exciting circuit is provided. A control circuit that is responsive to the action of the welding electrode is provided for causing the said switching element to interrupt the exciting circuit of the generator so that the weld is completed by energy supplied from the generator during the collapse of the magnetic field of the generator field winding.

2,486,281—Arc Cutting of Metal and Electrode Therefor—Curtis R. Henry, Youngstown, Ohio, assignor to Valley Mould & Iron Corp., Hubbard, Ohio, a corporation of New York.

This cutting method relates particularly to ferrous metal castings having carbon present in the form of free graphite throughout the metal. The method comprises subjecting the metal to an electric arc from a coated ferrous electrode operated at an amperage of at least 300.

2,486,319—Apparatus for Making Closely Spaced Spot Welds—Eric J. Opitz, Pleasant Ridge, Mich., assignor to General Motors Corp., Detroit, Mich., a corporation of Delaware.

This special type of apparatus is adapted to produce a line of spot welds with a minimum of spacing between the welds. A plurality of support brackets are provided on opposite sides of a vertical plane coinciding with the proposed line of the welds. Each bracket positions a plurality of electrodes which are pivotally supported thereon. Insulated tracks are associated with the electrode support means provided and power means engage with the insulated tracks to move the electrodes to and from a work-engaging position.

2,486,331—Spot Welding Apparatus—Robert A. Shields, Bloomsburg, Pa., assignor to American Car & Foundry Co., New York, N. Y., a corporation of New Jersey.

This spot welding apparatus includes a frame having a plurality of sides, with an electrode tip being carried on at least three of said sides. Each tip is shiftable along its respective side to vary the relative spacing and angular relationship of the tips and a source of welding current is connected to the electrode tips by flexible leads.

2,486,592—Welding Machine—B. H. Forssmark and Lewis M. Headley, Warren, Ohio, assignors to The Federal Machine & Welder Co., Warren, Ohio, a corporation of Ohio.

This patented machine includes the combination of a revolvable member and means for maintaining the contour of the revolving member. Leaf spring means urge the contour maintaining means in a direction toward the revolvable member.

2,487,183—Welding Hood—Earl E. Rohlf, Milwaukee, Ore.

This special type of a welder's hood has a lower section with an upper section hinged thereto. Means are provided for opening the upper hood section and permit closing thereof by pressure from the chin of the wearer and release of such pressure.

2,487,392—Continuous Wire Fabric Welder and Method—Wm. S. Southwick, East Lynn, Mass., assignor to Thomson Electric Welder Co., East Lynn, Mass., a corporation of Mass.

This patent covers a specialized type of wire fabric welding device and method.

2,487,430—Flame Hardening Head—Edgar M. Fein, Wellington, Kans., assignor to Cardwell Mfg. Co. Inc., Wichita, Kans.

This flame-hardening head includes two elongated coolant chambers in the head. Conduit means connect individually to the different coolant chambers for supplying different types of quenching mediums thereto. Jet openings are formed in the head and connect to the coolant chambers.

2,487,462—Method of Electric Resistance Welding—Adolf Meyer, Kusnacht, Switzerland, assignor to Aktiengesellschaft Brown, Bovert & Cie, Baden, Switzerland, a joint-stock company.

Meyer's welding method includes the step of positioning a lower melting point metal in contact between the faces of two parts to be welded together and bringing an electric current to pass between the three metal members so as to melt the lower melting point material. After a substantially uniform resistance path is established across the entire surfaces of the two metal pieces to be welded together, the current passing therethrough is increased to remove the contact metal from between the metal faces to be welded and effect fusion of the surface layers of such faces.

2,487,848—Auxiliary Eye and Face Shield for Welding Helmets—Charles E. Bowers, Moylan, Pa., assignor to Fibre Metal Products Co., Chester, Pa., a partnership consisting of Frederick M. Bowers, Chas. E. Bowers and John W. Bowers.

This patent relates to an auxiliary eye and face shield that is pivotally mounted adjacent to the extremities of a strip which can itself be secured to the head gear of a welding helmet.

2,488,101—Electric Welding of Metal Strip—Donald Ross, London, England.

Ross' patented apparatus includes a metallic base that connects to one side of a transformer secondary winding and supports two adjacent but separated carbon electrodes. A bracket is connected to the other side of the transformer secondary winding and pivotally mounts two arms thereon with the arms each carrying a carbon electrode so that each of the two last-mentioned electrodes cooperate with a corresponding electrode on the metallic base. The two electrodes of each pair can be adjusted toward or away from each other.

LIST OF NEW MEMBERS

November 1 to November 30, 1949

ANTHONY WAYNE

Martin, Kenneth D. (B)
McLaughlin, John W. (B)
Menzel, William F. (B)

BIRMINGHAM

Bertossa, Robert C. (C)
Owens, E. Ray (B)

BOSTON

Purcell, Ernest, Jr. (C)

CHICAGO

Donahey, Herman W. (B)
Pozdol, Frank J. (D)

CINCINNATI

Schuler, Carl J. (C)

CLEVELAND

Gibbons, Thomas J. (C)

COLUMBUS

Bliss, Willson V. (D)
Edwards, Walter R. (D)
Myers, Robert David (D)
Odell, Richard E. (D)
Reippel, Perry J. (C)
Reeves, Henry A. (D)
Schroeder, Victor C., Jr. (D)

DALLAS

Dwyer, E. A. (C)

DAYTON

Luebben, W. R. (D)
Ruf, Charles E. (D)
Speece, Howard P. (D)
Wester, Daniel Edward (D)
Yamanishi, M. G. (D)

HARTFORD

Zdon, Victor J. (C)

INDIANA

Pollack, Alexander P. (B)

HOUSTON

Caloway, Charley C., Jr. (C)

KANSAS CITY

Demees, George G. (B)

LEHIGH VALLEY

Gurm, Rudolph (C)
Posh, John F. (B)

LONG BEACH

Hamilton, William (C)
Schuyler, Glenn G. (C)
Williams, F. H. (C)

LOS ANGELES

Lanier, S. R. (C)
Rogers, C. E. (A)

LOUISVILLE

Corcoran, M. P., Jr. (C)

MAHONING VALLEY

Oven, Lief (B)
Pence, William (C)
Watson, Frank C. (B)

MARYLAND

Schmid, J. L. (C)

MICHIANA

McLaughlin, George (C)

NEW JERSEY

Axtell, A. C. (B)
Brown, Kenneth L. (C)
Conlon, Joseph R. (C)
Doyle, Vincent (B)
Engle, Gilbert B. (B)
Horr, William L. (C)
Hunt, Fred C. (C)
Rhoades, James E. (C)
Sippie, Leon (C)

NEW YORK

Heck, John W. (B)
Sapega, August (D)

NIAGARA FRONTIER

Payne, William M. (B)

NORTHERN NEW YORK

Baldwin, Donald R. (C)
Gillie, Roy P. (D)

NORTHWEST

Frederickson, Richard (C)
Fuhrman, Ralph W. (D)
Gamache, William P. (B)
Newton, L. C. (B)

OKLAHOMA CITY

Albertson, Phil E. (D)
Atkinson, Robert V. (D)
Chastain, Johnny J. (D)
Lancaster, Ezra O., Jr. (D)
McDermott, Ralph E. (D)
Sharkey, Jean H. (D)

PEORIA

Richart, N. L. (C)

PHILADELPHIA

Stuffer, William S. (C)

PITTSBURGH

Cohen, Harold (B)

PORTLAND

Smith, Warren L. (B)

PUGET SOUND

Deady, J. E. (C)
Doe, Percy E. (C)
Douvier, Frank J. (C)
Elliott, Clarence M. (C)
Frye, Henry G. (C)
Koischner, Richard H. (C)
Lee, Chester (C)
Patnik, Al (C)
Pederson, A. Vic (C)
Strong, Charles A. (C)

ROCHESTER

Conklin, Lawrence E. (A)
Cox, Gilbert L. (B)

SUSQUEHANNA VALLEY

Carleton, John V. (C)

SYRACUSE

Benz, Ray (C)
Shafer, John (C)

TOLEDO

Gass, Robert C. (D)

TRI-STATE

Flanders, Frank (C)

WESTERN MICHIGAN

Buchner, Melvin (B)
Cooper, James R. (C)
Dye, Van (B)
Gehman, John H. (C)
Schemerhorn, Marvin M. (B)

NOT IN SECTIONS

Baker, John C., Jr. (D)
Ballou, C. J. (D)
Brown, Lee P. (D)
Calvin, Bill (D)
Denison, Charles E. (D)
Dickson, B. B. (D)
Dombaugh, Keith D. (D)
Engle, Charles R. (D)
Ericson, Gene S. (D)
Evans, Duane E. (D)
Graves, Albert H. (D)
Hakanson, Harold R. (D)
Headrick, Lewis L. (D)
Keene, Arthur William Jr. (D)
Lopez, Gerardo (B)
Marti-Balaguer, Leopoldo (D)
Morgan, Robert K. (D)
Schmidt, Ernest J. (D)
Schroll, James R. (D)
Sheets, Don R. (D)
Thowe, Harry M. (D)
Turner, Julius F., Jr. (D)
Wilson, Philip W. (D)
Yeates, Richard Potter (D)

Members Reclassified

During the month of November

ANTHONY WAYNE

Scheiber, Benedict H. (C to B)

WASHINGTON

McPherson, Bernice M. (C to B)

SECTION ACTIVITIES

prepared by C. M. O'Leary

Anthony Wayne

The November meeting of the Anthony Wayne Section was held on Friday, the 11th, at the Fort Wayne Chamber of Commerce Bldg. Following a Buffet Dinner which started at 6:30 P.M., the members and guests were entertained by Richard Stoner, Magician. His repertoire of magic tricks and slight of hand was exceptionally good.

J. Colin Smith, regional manager of the Aluminum Company of America, then introduced the technical speaker for the evening, G. O. Hoglund of Alcoa. He first presented an Alcoa movie pertaining to the manufacturing of aluminum plates, sheets, foil, castings, forgings, etc. He then spoke on "Welding the Aluminum Alloys," illustrating his talk with slides.

Mr. Hoglund explained the various alloying elements used with aluminum, their effects on the physical properties, and the weldability of the consequent alloys. He discussed arc welding, gas welding, heli-arc welding, resistance welding, brazing and other welding applications of aluminum and explained where and how these various procedures should be used.

Mr. Hoglund ended his talk with a film on Aluminum Brazing. A most interesting discussion period followed. Following the close of the meeting, a number of those in attendance stayed to talk with Mr. Hoglund on their personal problems relative to his subject and examined a number of samples furnished by Alcoa.

There were 51 in attendance at dinner and 62 at the technical session. It was the consensus of opinion among the "regulators" that this meeting was one of the best to date.

Arizona

The Arizona Section held its monthly meeting for the month of November on the 16th at the Westward Ho Hotel, Phoenix. There were about 35 at the dinner meeting. After dinner Lawrence Tenes gave a very interesting talk on cost control in welding. Mr. Tenes is connected with the Consolidated Western Steel Co. in Phoenix. He has had a great deal of background in his subject having worked for a number of years for the General Electric Co., Schenectady. His talk prompted a lively discussion which lasted for an hour and a half. Following Mr. Tenes talk, four films furnished by Alcoa on the various means of welding aluminum were shown.

Atlanta

The Atlanta Section held its first meeting of the 1949–50 season on October 20th. Speaker was Ben Askew of the Georgia Power Co., who spoke on "Power Supply for Welders."

The meeting was presided over by Walter Campbell of the General Electric Co., program committee chairman. Approximately 25 were in attendance and enjoyed a fine dinner and a splendid talk.

Birmingham

November dinner meeting was held on Thursday, the 10th, at the Redmont Hotel. The speaker was Lew Gilbert, Editor of *Industry and Welding*, whose subject was "Check Your Maintenance Welding." Mr. Gilbert has had wide experience in manual and automatic welding and is author of several papers on the subject, the most recent being "How to Choose and Use the Correct Electrode."

Cincinnati

The regular monthly dinner meeting of the Cincinnati Section was held on September 27th at Manchester Hotel, Middletown, Ohio.

Following dinner there was a plant visit to The United Welding Co.: a new and very well-equipped plant for fabrication of heavy weldments. Diesel engine frames and machine bases are some of the items manufactured by the United Welding Co.

The October meeting was held on the 25th. Fred Turrill, President of Turrill, Inc., also operator of a school for the teaching of welding operators, gave a fine talk on his experiences in this field, what they have accomplished and what the future holds in store for welding schools.

Cleveland

The regular monthly dinner meeting was held on November 9th at the Cleveland Engineering Society. Dinner speakers were Miss Cheerful Harris and Miss Bertha Merriman, who gave an illustrated talk on "Postwar Europe."

Technical speaker was C. C. Peck, of Cecil C. Peck Co., who spoke on "Tooling for Automatic Arc Welding." A film "Designing Machinery for Arc Welding" was shown through the courtesy of The Lincoln Electric Co. About 150 members and guests thoroughly enjoyed the meeting.

Colorado

W. R. Grunow, Development and Sales Engineer, Allegheny-Ludlum Steel Corp., was the guest speaker at the November 8th meeting held at Silver Wing Inn, Denver. His subject "Welding of Stainless and Chrome Nickel Steels" was of considerable interest to the audience. Three reels of film on Stainless Steel were shown in conjunction with the talk.

This was the first meeting where the new officers took office—J. L. Fry as Chairman and E. F. Jacobi as Vice-Chairman. The new officers and membership have pledged themselves to build up the Colorado Section with additional members.

Columbus

The November 11th meeting of the Columbus Section was a great success. Dinner speaker Wm. W. Murray, Jr., Chairman of the Board of Trustees of the National Certified Pipe Welding Bureau, spoke on the activities of the Bureau. Mr. Murray was plied with questions from all sides on the what, wheres and whys of the Bureau.

E. P. Everhard, Chairman of the Technical Committee of the National Certified Pipe Welding Bureau, spoke on the Current Practice in Erection of Welded Piping. He explained the various tests welders must make to be able to weld on pressure piping. He also talked of the erection practices of the Wm. A. Pope Co., Chicago.

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- Edgcomb Steel Company
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- Williams & Company, Inc.

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- Pacific Metal Company

Rochester, New York
- Braco-Mueller-Huntley, Inc.

San Francisco, California
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Dallas

C. B. Voldrich, Chief Welding Engineer, Battelle Memorial Institute, addressed the November 16th meeting, on "Recent Developments in the Welding of Aluminum." Forty-two illustrative slides were presented with Mr. Voldrich's lecture. The entire attendance was especially well pleased with the newness of information disclosed by the speaker.

Dayton

The November 16 meeting of the Dayton Section consisted of a tour through the Delco Products Division of General Motors in Dayton. The group of seventy-five members and guests found the inspection trip most interesting and educational.

In the fractional horsepower and industrial motor divisions, the group saw in operation stator blanking, stator assembly, stator winding, rotor assembly, final assembly and testing. The many interesting welding operations in this division included motor frame seam welding, rotor and ring automatic carbon arc welding, stator hot riveting and induction heating of rotors.

In the shock absorber division, the tour included shock chamber fabrication, piston assembly and final assembly. Among the welding operations in this division were spot welding mounting rings and studs to end cups, rolling and seam welding tubing, induction hardening piston rods, seam welding seal covers to reservoir tubes and seam welding dust shields to cover plates.

The power distribution system for the plant was also described to the group. The power transformers are mounted in a penthouse atop the main building, from which the welders are fed directly through concentric welding cable, keeping line drop to a minimum.

After the tour, the guests were treated to refreshments.

Detroit

The regular monthly dinner meeting of this Section was held on November 11th in the Engineering Society of Detroit. Martin P. Korn, consulting engineer, outlined in simple language the structural behavior picture of the rigid frame. Illustrating his lecture with a fast-moving panorama through the use of sketches and slides a history of living structures representing yesterday, today and tomorrow. Both riveted and welded frames were contrasted to show why welded frames are better, smaller and therefore less expensive. He focused a spotlight on each of their distinguishing characteristics in a manner which proved most provocative and highly educational to both professionals and students alike. Mr. Korn built his first rigid structure of concrete as long ago as 1910 and he has been a student of the rigid frame ever since.

Hartford

The November dinner meeting was held on the 17th at the Rockledge Country Club, Hartford. A. N. Kugler, Mechanical Engineer, Technical Sales Division, Air Reduction Sales Co., presented an interesting talk on "Aircomatic Welding—A semiautomatic inert Arc Welding Process."

Houston

The Houston Section held its October dinner meeting on the 20th at the Ben Milam Hotel. J. E. Young, Jr., of the General Metallizing Co., spoke on the subject, "Metallizing." A lively discussion followed.

A movie, "Football Hilites of 1948" was shown through the courtesy of the Humble Oil Co.

The November dinner meeting was held on the 17th at the Ben Milam Hotel. C. B. Voldrich of the Battelle Memorial Institute, spoke on the "Recent Developments in the Welding of Aluminum." Interesting discussion followed.

A movie "Trip Through Alaska" was shown through the courtesy of the Gulf Oil Co.

Indiana

The September 23rd dinner meeting was held at the Citizens Gas and Coke Utility, Prospect St. Plant, Indianapolis. A talk on "The Manufacture of Coke and Gas" was given by Karl Kick. A moving picture was shown, followed by a plant tour, which was very interesting.

The October 28th dinner meeting was held in the Delco-Remy Plant Cafeteria, Anderson. Plant tour was followed by a talk by Joe White, Horn Engineer of the Delco-Remy Co., on "The Development of the New Horn with Particular Reference to Welding Applications."

Trip and talk were extremely interesting due to the unusual welding applications with respect to the Horn manufacture. Through use of Resistance Welding, cost has been reduced in a number of parts, number of operations and almost total elimination of adjustment.

The November 18th dinner meeting was held at Buckley's Restaurant, Cumberland, Ind.

Technical speaker was R. M. Wilson of the International Nickel Co. Mr. Wilson's subject was the "Welding of Nickel and High Nickel Alloys." A film on the subject was also shown.

The film, while of great interest, covers a lot of ground, and would require several showings to get the most benefit of it. It starts from the ore through all types of refining and processing for a number of types of nickels and nickel alloys.

Lehigh Valley

The regular monthly meeting of the Lehigh Valley Section was held on Monday, December 5th, at the Hotel Bethlehem, Bethlehem, Pa. J. R. Fairhurst, Vice-Chairman, presided. A. B. Kime, regional Supervisor of the Ransome Division, Worthington Pump and Machinery Corp., Dunellen, N. J., gave an illustrated talk, "Positioning for Welding."

Mr. Kime discussed the increased production by the use of positioners, describing various typical applications where all welding can be done down-hand with larger electrodes, making possible a reduction in welding time per unit. A lively discussion period followed the talk.

A dinner meeting preceded the technical session and a sound film entitled, "Lukenweld" was shown through the courtesy of the Lukens Steel Co., Coatesville, Pa.

Los Angeles

Thursday evening, November 17th, the Los Angeles Section held its regular monthly dinner meeting jointly with the American Society for Metals.

The speaker was Hugo W. Hiemke, owner of California Alloy Products Co., and welding consultant of South Pasadena, Calif. Mr. Hiemke spoke of the subject, "Welding of Products from the Metallurgical Viewpoint."

With the aid of slides, manufacturing procedures employed in many local plants were shown and the metallurgical problems encountered due to welding were discussed.

During the question-and-answer session following the talk, considerable interest was shown in alloy welding problems which was expertly handled by the speaker.

Michiana

A joint dinner meeting of the Michiana Section, A.W.S., and the Notre Dame Section, A.S.M., was held on Wednesday, November 9th, at Notre Dame Dining Hall, South Bend, Ind.

"Of all the brazing furnaces installed by our company in plants making materiel for the last war, not one was returned to the furnace pool at the close of hostilities." This statement was made by N. K. Koebel, Lindberg Engineering Co., Chicago, the speaker, and gives some idea of the favor which this method of metal joining has found in the last few years.

Mr. Koebel gave a general résumé of the field of furnace brazing, comparing it to torch and induction methods, and outlining the advantages of each. He also gave the uses, advantages and disadvantages of the various types of brazing materials, copper, brass, silver solders, phosphorus copper and aluminum. A number of slides were shown illustrating many typical jobs which have been furnace brazed quickly and cheaply.

Louisville

Van Rensselaer P. Saxe, Consulting Engineer, Baltimore, Md., was the guest speaker at the November 22nd meeting. His talk on the subject of "Some Interesting Welded Structures" was well illustrated with lantern slides showing many recent arc-welded structures and buildings.

Mr. Saxe pointed out that in spite of the reluctance of some steel fabricators and structural engineers to design for arc welding, the method had proved to be both safe and economical. On one large building a saving of $69,000 was made by changing from a riveted design to an arc-welded design. One eastern city found that 20% could be saved on the cost of the steel girders for a speedway when fabricated by arc welding rather than by riveting.

After a discussion period following the talk, a movie film was shown entitled "Atomic Power."

The evening closed with a social hour and a Dutch lunch.

Milwaukee

The November meeting was held on the 18th, one week early on account of the holiday. Dinner at the Ambassador was attended by about 50 members. Following the dinner a talk on making Kentucky rifles was presented by E. G. Wolf of the Milwaukee Museum Staff. Colored slides were used to illustrate it. Unfortuntely, the welding of the barrels, which is done by hand, could not be shown.

The technical talk was presented by LaMotte Grover who discussed the fabrication and erection of welded bridges, buildings and freight cars with special reference to some of the European bridges that had failures. Mr. Grover pointed out that the year 1936 was a significant one in the structural welding field as many of the really modern applications of welding to structural steel fabrication were begun at that time. Mr. Grover's talk was of additional interest in that he reviewed the work that has been done in developing means of fastening girders in buildings and he showed examples of recent methods.

The members of the Milwaukee Section who competed with South Bend, Peoria and Indiana Sections, at the Chicago Section's quiz program on the same night as the above meeting, were second in scoring, winding up a few points behind Indiana. The quiz team reports a very interesting evening with excellent questions.

The Milwaukee Section held a smoker on December 2nd, for members and guests. Nearly 100 turned out to enjoy the beer, entertainment and refreshments.

New Jersey

The following is the schedule of meetings for the remainder of the season of the New Jersey Section:

JAN. 17, 1950: Speaker from Allis Chalmers Co.—Joint Meeting of A.S.M.E. & A.W.S., "Gas Turbine Power Plant."

FEB. 21, 1950: R. D. Thomas, Arcos Corp., "Welding of Stainless Steel."

MAR. 21, 1950: J. Randall, Ford Motor Co., "Welding in Automobile Industry."

APR. 18, 1950: J. Lyell Wilson, Quiz Program—"Battle of the Sections," New, York, Philadelphia, Bridgeport and New Jersey.

MAY 16, 1950: To be announced.

New York

The main event of the November 15th meeting of the New York Section was the stimulating talk, "Designing for Welding" presented by Thomas J. Crawford, Consulting Engineer, Progressive Welder Co., Detroit, Mich.

Mr. Crawford's discussion, starting with the rudiments of proper design for welding, developed the thesis that good welded design considered economic factors in addition to the purely service and strength requirements. He stressed the desirability for designers following a job through fabrication in the shop and so be able to alter the design where necessary to improve ease of fabrication in future production. He pointed out that unless this was done all too frequently designers did not profit by past mistakes. He noted that when changes had to be made on the job, often they were not recorded on the drawings, thus permitting the same errors to occur in the future. Mr. Crawford concluded his talk by showing some slides of poorly designed weldments and indicated how it was possible to modify the designs to permit easy and less costly fabrication.

S. A. Greenberg, Technical Secretary, AMERICAN WELDING SOCIETY, was the Technical Chairman at the meeting, and led the discussion at the conclusion of Mr. Crawford's talk.

The technical session was preceded by dinner at Schwartz's Restaurant, 54 Broad St., New York. For the After-Dinner Program, members and their guests heard F. J. Socey, Jr., free-lance weather prophet, present a talk, "The Weatherman Speaks." Mr. Socey described his method of long-range weather forecasting and told the weather to expect this winter.

The arrangements for this meeting were handled by H. R. Clauser, Program Chairman.

Northern New York

The November 17th meeting of the Northern New York Section was held in the Welding Section of the Schenectady Works Laboratory of the General Electric Co. The meeting started at 7:30 P.M. when R. W. Clark gave a brief description of the type of work which the Welding Laboratory does.

Next, the members and guests, of which there were 60 present, were divided into small groups and shown through the laboratory. The following processes were demonstrated: Micro butt welding, use of projection welding aluminum with and without slope control, flash welding of heavy sections, powder cutting of stainless steels, submerged arc welding, inert-arc welding, induction brazing with automatic water-quench cycle and resistance brazing of small parts. Following the tour and demonstrations, a question-and-answer period took place.

I. W. Johnson, who is in charge of the resistance welding section of the Laboratory, then gave a talk on "Slope Control in Spot and Projection Welding." This talk was based on the paper which Mr. Johnson presented at the A.W.S. Annual meeting. Mr. Johnson was awarded second prize for this paper in the R.W.M.A. contest.

Northwestern Pennsylvania

A joint meeting with the Warren Foreman's Club was held on November 14th in Warren, Pa., at the Warren Y.M.C.A. Dr. Allen A. Stockdale, N.A.M., presented an excellent talk on "Team Work Wins."

Northwest

The following is the meeting schedule for the remainder of the season. To be held in the Lodge Room, Covered Wagon, 114 S. 4th St., Minneapolis—Happy half hour, 6:00 P.M.; dinner, 6:30 P.M.; Meeting, 8:00 P.M.

FEB. 13, 1950: Lew Gilbert, Editor, *Industry and Welding*, "Check Your Maintenance Welding."

MAR. 13, 1950: C. B. Voldrich, Chief Welding Engineer, Battelle Memorial Institute, "Weldability of Steels."

APR. 10, 1950: Patrick S. Doyen, Field Engineer, Welding Equipment and Supply Co., "Tool and Die Welding."

MAY 8, 1950: Annual Social Meeting.

Oklahoma City

The November 15th dinner meeting was held in the Biltmore Hotel Coffee Shop. C. B. Voldrich, of Battelle Memorial Institute presented an interesting, clear-cut address on "Recent Developments in the Welding of Aluminum." Lively discussion followed.

Philadelphia

The November 21st dinner meeting held at the Engineers Club with 109 members present was a continuation of the fine enthusiasm and success that has attended each of the previous meetings this year.

In place of the usual coffee speaker the film "Adventure in Research" by the Westinghouse Research Division was shown. While not of a serious technical nature, it was very interesting and helped remind those present that there will always be new things to come.

James F. Lincoln, President of The Lincoln Electric Co., opened the meeting with a prepared talk on "Welding." He covered the various standards, requirements and considerations that govern welding as they now exist and then gave his recommendations for necessary changes and modifications. This subject received a short discussion from the floor.

Then in answer to questions from the floor, Mr. Lincoln explained at some length the operation of the highly successful incentive plan at The Lincoln Electric Co., and his ideas in regard to the general operation of any such plan. The questions and discussion of this subject were halted only by the necessity of closing the meeting.

However, informal discussion continued while the refreshments were served and enjoyed by all.

Pittsburgh

The November 16th meeting was held at Hotel Webster Hall, Mellon Institute. Thirty-five were at the dinner. Ninety-six attended the technical session. Norman G. Schreiner of The Linde Air Products Co., New York, gave a clear-cut talk on "The Effect of Various 'Flux' and Electrode Compositions on Submerged Arc Welding." A film "Oxygen in the Open Hearth" was shown in conjunction with the paper. C. J. Burch of The Linde Air Products Co., gave explanatory remarks on the film. Both were well received and lively discussion followed.

Important announcements regarding future meetings, committee meetings and meetings of other technical groups were

made as well as presentation of a gift to the speaker—a Monel "Norma" pencil, engraved.

Puget Sound

The October dinner meeting was held on the 13th at the New Washington Hotel, Seattle, with an attendance of about 60.

A Coffee Talk feature was a review of the paper "Economic Electric Arc Welding" which appeared in the September JOURNAL. This paper by Mr. Oestreicher of the Harnischfeger Corp., was reviewed by E. M. Rutt, local Welding Engineer of the same company. A very good discussion followed.

The main speaker was C. A. Ross of the Puget Sound Navy Yard, Bremerton, Wash. His subject, "Welding Inspection" provoked an unusual amount of enthusiastic discussion by the audience.

Present was Prof. Gilbert S. Schaller, a Director, who gave a short talk outlining the aims of the SOCIETY.

Rochester

The Rochester Section held its monthly meeting on Monday, Nov. 21, 1949. A dinner preceded the meeting at Guy Michael's Restaurant.

The meeting was called to order by Chairman Walter Kazoraski, who named and introduced the new members. A movie, entitled "Seventh Wonder" showed the Panama Canal and the manipulation of the locks, a very impressive engineering achievement.

E. A. Basilio, Chief Metallurgist at General Railway Signal Co., Rochester, N. Y., was guest speaker. He was introduced by Vice-Chairman Herbert Fetter. Mr. Basilio's subject was "Hard Facing."

The speaker outlined the subject by pointing out that whereas nature renews herself by growth, man-made machines wear out, and that hard facing was one good method by which more economical use could be made of available materials.

The subjects of "wear" and "hardness" were defined and the limitations inherent in the definitions and lack of precise knowledge of some of the factors involved were discussed. The importance of evaluating all factors and service conditions known to affect the wear of the part in question prior to choosing any one of several types of hard-facing materials was stressed.

A number of slides and wall charts were shown which indicated compositions, physical and mechanical characteristics and microstructures of typical materials in each of the four or five main groups of hard-facing materials.

A discussion period followed.

Mr. Basilio's address was well received and applauded by all with a rising vote of thanks.

San Francisco

Dinner meeting of the San Francisco Section was held on Monday, November 28th, at the Engineers Club.

Processes of welding pipe at the new pipe mill of Basalt Rock Co.'s plant at Napa and the Kaiser mill at Fontana, soon to be placed in operation, were outlined by Richard Aubrey, assistant to the vice-president in charge of operations at Kaiser Steel Corp.

Mr. Aubrey stressed the importance of careful testing all the way through the processes, stating "From the time the ore hits our plant it goes through 167 tests we think have something to do with making pipe."

He described the magnetic tester, whereby any defect is shown by a line in powder after the pipe has passed through the 5-roll straightener, as "one of the latest developments in high-quality resistance welded pipe," explaining that the test is a Magna-Flux method of handling pipe continually as fast as it is produced.

R. L. Asquith, assistant general sales manager for Kaiser Steel Corp., reviewed marketing of pipe, pointing out that the Fontana mill is producing today at design capacity, turning out 60% in galvanized pipe which ends up as building material and the other 40% as black pipe for sale to the utilities.

A film showing production of steel and steel products, "More Things for More People" concluded the program.

Tri-State

The November 17th dinner meeting was held at Bockelman's Evansville, Ind. Harold Baldwin of LeTourneau, presented an instructive talk on "Welding Codes, Procedures, Electric Rods and Jigs." Slides were used for illustration.

Washington

Following is the schedule of meetings for the remainder of the 1949–50 season.

JAN. 31, 1950: Club 400, 8:00 P.M., "Engineering and Code Requirements for Welded Pressure Vessels." Harry C. Boardman, Director of Research, Chicago Bridge and Iron Co.

FEB. 28, 1950: Club 400, 8:00 P.M., "Welding of High-Temperature Alloys," R. D. Thomas, President, Arcos Corp.

MAR. 28, 1950: "Prefabrication of Steel Homes and Mill Buildings," Robert H. Pool, Superintendent, Electrical Dept., Truscon Steel Co.

APR. 24, 1950: Thirteenth Anniversary Dinner. Speaker: O. B. J. Fraser, Director of Technical Service on Mill Products, International Nickel Co., and National President, AMERICAN WELDING SOCIETY.

Worcester

Seventy-five members and guests of the Worcester Section turned out for the November 30th meeting to hear Lew Gilbert, Editor of *Industry and Welding*, present a paper on Maintenance Welding.

Mr. Gilbert contended that maintenance welding, long relegated to a position of unimportance—as compared with production welding—has finally been recognized as a major factor in production. He pointed out that in the maintenance of machinery and equipment, welding is often more important from a standpoint of time saved than that of actual material saved. Repairing broken machine parts, which cost only a fraction of the price of a new machine, results in substantial savings; but of more importance is the fact that repairs can be made immediately, saving days and even weeks of waiting for replacement parts.

Slides showing activities of maintenance welding departments of such industries as food, rubber, paint, drugs, etc., proved of great interest to the audience. Emphasis was placed on safety and comfort of the welding operators, resulting in increased production.

A film "The Making of the New York Yankees" rounded out a very excellent program.

WELDING METALLURGY

The internationally known book on the above subject originally written by Henry & Claussen has been completely revised, enlarged and brought up to date by G. E. Linnert. A book of 505 pages, handsomely bound, price $2.50. Order your copy now! American Welding Society.

WELDING RESEARCH COUNCIL

of the Engineering Foundation

Sponsored by the American Welding Society and American Institute of Electrical Engineers American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers American Society of Mechanical Engineers, and Society of Naval Architects and Marine Engineers

Supplement to The Welding Journal, January, 1950

Welding Research Council Elects New Officers

AT A MEETING of the Welding Research Council held in New York on November 3rd, Harry C. Boardman, who has been serving as Vice-Chairman of the Council, was elected Chairman. Dr. Comfort A. Adams, who has been serving as Chairman of the Council since its inception, was elected to the newly created position of Honorary Chairman. Dr. A. B. Kinzel was elected as Vice-Chairman of the Council.

About a year ago Dr. C. A. Adams attained the age of 80 and asked the Council to make preparations for relieving him of the detailed work in connection with the Chairmanship of the Council.

In 1935 the Welding Research Council was created by The Engineering Foundation at the request of the AMERICAN WELDING SOCIETY and the American Institute of Electrical Engineers to foster and stimulate cooperative research in the welding field and to devote its first attention to critically reviewing the welding literature. In order to concentrate all of the welding research activities into one body the AMERICAN WELDING SOCIETY discharged the American Bureau of Welding and transferred the University Research Committee to the Welding Research Council. Some uncompleted activities of the Structural Steel Committee of the American Bureau of Welding were also transferred.

In setting up the Welding Research Council the Engineering Foundation felt that the first task was to critically review the literature and make available in readily condensed usable form the research information which then existed in many journals published in several languages. This was a gigantic undertaking. An initial appropriation of $5000 was made by The Engineering Foundation with the understanding that the second year's appropriation of $5000 by the Foundation would be matched 2 to 1 by Industry. The first year's budget was therefore $5000; the second year's budget jumped to more than $20,000. The budget grew rapidly and in recent years has amounted to well over one-quarter of a million dollars annually.

Actually the cash budget of the Council represents only a fraction of its total operations. A great deal of the research work is done in the laboratories of companies with which members of Project Committees are affiliated. These laboratories take over certain portions of the program without any cash transfers. The Council cooperates with many government agencies, notably the Ship Structure Committee. The reports of the Ship Structure Committee are also cleared through the publications of the Council. In total the value of research so published amounts to more than one million dollars a year. Even this figure does not include the time and travel of the 600 scientists affiliated with the various projects of the Council.

In order to prevent unnecessary duplication of effort, cooperative arrangements have been established with a similar body in Great Britain, and there is a complete exchange of information and results between the two bodies so that the Research Workers and Contributors to the Welding Research Council obtain the benefit of the research work carried out by the British Welding Research Association. Contacts have been established with other countries, but they have not as yet materialized to the degree of cooperation which prevails with Great Britain.

In 1946 the sponsorship of the Welding Research Council was enlarged to include the other founder societies, the American Society of Mechanical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, and, also, the Society of Naval Architects and Marine Engineers. Actually, however, there are a number of other societies that participate in the work of the Council, including the American Society for Metals and the American Society for Testing Materials.

The Welding Research Council acts as a welding research department for a number of trade associations such as the American Iron and Steel Institute, the American Institute of Steel Construction, the American Petroleum Institute, and the Resistance Welder Manufacturers' Association.

THE ORGANIZATION

The organization of the Council is quite simple. Some 20 key executives serve as the Council members. This body determines the broad general policies of the Council, approves the initiation of new projects and defines their scope of activities, determines rules of procedure and approves of the annual budget. Detailed managerial operations are handled by a small Executive Committee. The scientific work is administered by carefully chosen eminent project committees. The present membership of the Council, as approved at the meeting on November 3rd, is:

Adams, C. A., *Honorary Chairman;* 417 W. Price St., Philadelphia 44, Pa.
Boardman, H. C., *Chairman;* Director of Research, Chicago Bridge and Iron Co., 1305 W. 105th St., Chicago 43, Ill.
Kinzel, A. B., *Vice-Chairman;* President, Union Carbide and Carbon Research Labs., Inc., 30 E. 42nd St., New York 17, N. Y.
Barlow, E. H., Consulting Engineer, Standard Oil Development Co., 15 W. 51st St., New York 19, N. Y.
Brown, Edwin H., Vice-President, Allis-Chalmers Mfg. Co., Milwaukee 1, Wis.
Crowe, J. J., Assistant Vice-President, Air Reduction Co., Murray Hill, N. J.
Frankland, F. H., Consulting Engineer, 99 Wall St., New York 5, N. Y.

Fuller, T. S., Engineer-in-Charge, Works Lab., General Electric Co., Schenectady 5, N. Y.
Green, Walter L., Vice-President, American Bureau of Shipping, 45 Broad St., New York 4, N. Y.
Loeb, Carl M., Jr., Vice-President, Climax Molybdenum Co., 500 Fifth Ave., New York 18, N. Y.
Magos, John P., Director of Research, Engrg. & Research Div., Crane Co., 4100 S. Kedzie Ave., Chicago 5, Ill.
Maier, Oscar C., Director of Research, Pullman-Standard Car Mfg. Co., 1414 Fields St., Hammond, Ind.
Murray, A. V., President, Scaife Co., Oliver Bldg., Pittsburgh 22, Pa.
Pew, Arthur E., Jr., Sun Oil Co., 1500 Walnut St., Philadelphia 2, Pa.
Reinhardt, G. A., Director of Metallurgy and Research, Youngstown Sheet and Tube Co., Youngstown, Ohio.
Somers, R. E., Research Engineer, Bethlehem Steel Co., Bethlehem, Pa.
Spackman, G. D., Vice-President in Charge of Operations, Lukens Steel Co., Coatesville, Pa.
Spraragen, W., Director, Welding Research Council, 29 W. 39th St., New York 18, N. Y.
Walker, Henry S., Director of Research, Detroit Edison Co., 2000 Second Ave., Detroit 26, Mich.
Weigel, A. C., Vice-President, Combustion Engineering-Superheater, Inc., 200 Madison Ave., New York 16, N. Y.
Zimmerman, R. E., Vice-President, U. S. Steel Corporation of Delaware, 436 Seventh Ave., Pittsburgh 30, Pa.

At this meeting the following members were elected to serve as an Executive Committee: H. C. Boardman, *Chairman;* A. B. Kinzel, Vice-Chairman. *Other Members:* C. A. Adams, *Honorary Chairman;* T. S. Fuller, C. M. Loeb, Jr., A. V. Murray and A. C. Weigel. W. Spraragen continues to serve as Director.

There follows a brief biography of the newly elected officers.

Dr. Comfort A. Adams

Dr. Comfort Avery Adams the newly elected Honorary Chairman, was born in Cleveland, Nov. 1, 1868. He received the degree of B.S. in 1890, a degree of B.E. in 1905 and the honorary degree of Doctor of Engineering in 1925 from the Case School of Applied Science.

Dr. Adams is an Engineer, Educator and Scientist.

He has won many important distinctions. His most recent one is the 1940 Lamme Medal for his work in electrical machine design. He was the first recipient of the Samuel Wylie Miller Medal. He is a member of the National Academy of Sciences and an Honorary Member of the American Welding Society. He was the first Adams Lecturer.

In order to speed up shipbuilding production in 1918, there was created a Welding Committee of the Emergency Fleet Corp. under the chairmanship of Dr. C. A. Adams.

Work done by the Welding Committee laid the foundation for the organization, after World War I, of the American Welding Society and of its affiliated research organization known as the American Bureau of Welding. Dr. Adams was the first president of the American Welding Society and the first Director of the American Bureau of Welding, which position he held until the Bureau was discharged and a Welding Research Committee organized under the Engineering Foundation in 1935. Dr. Adams was made Chairman of this Research Committee which position he held until this meeting.

C. A. Adams

In order to honor the Founder and First President of the American Welding Society, the Society in 1943 created a lectureship known as The Adams Lecture. The award is made annually by the Board of Directors to an outstanding Scientist or Engineer, and his lecture presents some new and distinctive development in the field of welding.

H. C. Boardman

Mr. Boardman, newly elected Chairman of the Council, is Research Director for the Chicago Bridge and Iron Co., Chicago, Ill., and is a past-president of the American Welding Society and also Honorary Member of the Society. Mr. Boardman is Chairman of the *Handbook* Committee, A.W.S.; member of the Boiler Code Committee, American Society of Mechanical Engineers. His technical society memberships include ones in the American Society of Civil Engineers, the Western Society of Engineers, the American Society for Metals, and the American Association for the Advancement of Science. He is also a member of Tau Beta Pi and Sigma Pi. He received the Miller medal for 1941.

Mr. Boardman was born in Plainfield, Ill., Apr. 29, 1887. He received his B.S. degree from the University of Illinois in 1910 and his C.E. from the same school in 1926. He holds an honorary E.D. from the South Dakota State School of Mines. From 1910 to 1916 he was a draftsman for the Chicago Bridge and Iron Co. Entering the Army as a private in 1916, he was discharged in 1919 as a major in the field artillery. From 1919 to 1922 he was in the automobile tire and accessory business in Kansas City, Mo.; from 1922 to 1924 he was engineer and superintendent of construction for the International Filter Co., Chicago, Ill.; and, from 1924 to 1926, served as an instructor in civil engineering at the University of Illinois. In 1926 he took the position which he now holds.

H. C. Boardman

He is the author of many technical articles published in various magazines and of the *Handbook on Arcs, Chords and Versines.*

Vice-chairman A. B. Kinzel

Dr. A. B. Kinzel, who was elected Vice-Chairman of the Council is President of

A. B. Kinzel

the Union Carbide and Carbon Research Lab., Inc., New York, received the Samuel Wylie Miller Memorial Medal in 1947.

Dr. Kinzel graduated from Columbia University, A.B., in 1919, Massachusetts Institute of Technology in General Engineering, 1931, and the University of Nancy, France, D.Met.Ing., 1922, where he received the degree of Doctor of Science in 1933. Before joining the Union Carbide organization in 1926, he had several years' experience as metallurgist with General Electric Co. and Henry Disston & Sons, and as lecturer of the advanced courses in metallurgy at Temple University, and as a consultant.

Dr. Kinzel is the author of many papers on the testing and welding of metals, on the metallurgy and physical chemistry of steel making, on the composition, physical properties and uses of ferroalloys and alloy steels, and on applied mechanics, and is co-author of the volumes on chromium in the "Alloys of Iron" series of monographs. He holds many patents in these fields.

Dr. Kinzel is now Vice-President of the American Institute of Mining and Metallurgical Engineers, and Past-Chairman of the Engineering Foundation Board as well as Chief Consultant in metallurgy to the Los Alamos Laboratories and the Argonne National Laboratories of the Atomic Energy Commission. During the war, in addition to his work for the Manhattan District, Dr. Kinzel was Senior Consultant on metals to the War Production Board, Chief Consultant on metals to the Enemy Branch of the Foreign Economic Administration, Project Supervisor of the War Metallurgy Committee, and served T.I.I.C. in England, France and Germany as head of the Metals Section (Assimilated Brigadier General).

Dr. Kinzel has lectured widely, including special lectures such as guest lecturer of the Society of Culture of the U.S.S.R. in Moscow in 1936, Adams Lecturer of the American Welding Society in 1944, and Campbell Lecturer of the American Society for Metals in 1947.

Spot Welding Nickel and Nickel Alloys

Spot weldability of various nickel alloys in dissimilar metal combinations are indicated and correct welding procedures are given

by Frank G. Harkins

Abstract

A study of the weldability of various nickel alloys in dissimilar metal combinations has indicated that successful spot welding can be achieved. That serious metallurgical and physical problems will be encountered in the joining of many combinations is evident. Particular attention is given material combinations which appear to be metallurgically incompatible with each other such as Monel-mild steel. Methods of causing the nugget to grow at the interface where the materials are of widely different physical properties are indicated. Tentative welding schedules for the various metal combinations are submitted.

INTRODUCTION

As A part of its regular program the A.W.S. Committee on Resistance Welding Nickel and Nickel Alloys has investigated the spot welding of:

Nickel to mild and lower-alloy steel.
Nickel to stainless steel.
Nickel to Monel.
Nickel to Inconel.
Monel to mild steel and 8630.
Monel to stainless steel.
Monel to Inconel.
Inconel to mild steel and 8630.
Inconel to stainless steel.
Inconel X to Inconel X.
Titanium to titanium.
Stainless steel to mild steel and low-alloy steel.

Frank G. Harkins is Welding Engineer, Solar Aircraft Co., San Diego 12, Calif.

The economic importance of many of these material combinations is somewhat obscure. For example, the joining of nickel to Monel appears to have little practical advantage other than expediency. However, the joining of such materials as Inconel, Inconel X, nickel and Monel to mild or stainless steel has economic importance. Many of these materials are selected for a given application because of their remarkable physical properties. These properties may be required only in localized areas rather than throughout the assembly. In these cases it is economically desirable to employ the high-alloy material where required and to complete the assembly with stainless, mild or low-alloy steel. The same is true where these materials are selected for decorative purposes.

While it is recognized that many of these material combinations are being welded on a production basis daily, little published information or classified data are available. It is a purpose of this paper to investigate the welding of these dissimilar materials with a view to establishing machine schedules. Another purpose is to attempt to evaluate the resulting weld between dissimilar materials.

A further purpose is to furnish engineers and designers with workable data which may be employed in the interest of product cost reduction and/or conservation of critical materials. To attempt to establish the optimum welding schedules for all gages and materials combinations does not appear to be practical at this time. It has been the decision of the committee to limit the study of the 0.063-in. thick materials thus eliminating the problems which arise in welding dissimilar thickness combinations. A few specific applica-

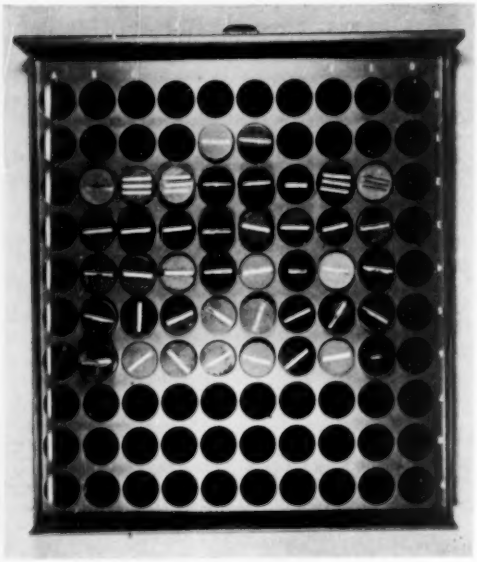

Fig. 1 General view of 42 mounted specimens used in the micro and macro examination of the test welds

tions involving the spot welding of different gage materials and the roll welding of the Monel-mild steel combination are included as matter of general interest.

EQUIPMENT

Equipment used for the experimental work consisted of one 45-kva., three-phase, direct current dry disk rectifier type spot-welding machine and one 100-kva., single-phase, 440 v., 60-cycle standard pedestal type spot-welding machine. Each machine is equipped with the low-inertia roller-bearing head which is necessary in insuring the fast follow-up pressure required by high-alloy materials. The operation of both machines was thoroughly checked before the experimental work was begun. Test equipment consisted of a welding force meter, a pointer stop ammeter, a pointer stop millivoltmeter, a cathode-ray oscilloscope, a six-element oscillograph and a time recorder.

DISCUSSION OF EQUIPMENT

It has been observed on many alloys and dissimilar material combinations that the use of high-inertia equipment results in welds containing radial cracks. The single-phase machine was equipped with a slope control. The proper evaluation of this device is beyond the scope of this paper although seemingly less sparking at the electrodes and less expulsion of metal occurred at the higher energy levels.

Material combinations which have caused difficulties on older types of equipment are readily weldable on low-inertia type machines whose secondary current has a low-wave front. A case in point is the spot and roll welding of the Monel-mild steel combination. The use of older equipments results in welds containing serious radial cracking (Fig. 14). In many cases, leakage directly through the weld from one outside surface to the other outside surface may be observed. Examination of the spot- and roll-weld specimens (Figs. 9 and 15) of this weld shows clean, sound, homogenous weld metal. Presumably, this weld is satisfactory as a result of the use of the low-wave front current plus the use of the low-inertia machine. It is not possible to state at this time the relative contribution of each feature.

MATERIAL PREPARATION AND ETCHANTS

Cleaning or buffing the surfaces of the material immediately before welding is recognized good practice. In this investigation the materials were prepared by polishing on a buffing lathe using No. 200 grit until a bright surface was obtained. This was a matter of convenience. Several chemical cleaners may be employed to good advantage on these materials.[2]

ETCHANTS

Since the materials involved in this investigation bear little relationship to each other in chemical composition and physical properties, it is apparent that no one etchant will produce satisfactory results on all of the material combinations. In a few cases it was necessary to use a double immersion technique to show the nugget structure in both metals. For example, in etching the Monel-mild steel specimens, it was necessary to first etch the mild steel in a 4% Nital solution. Sub-

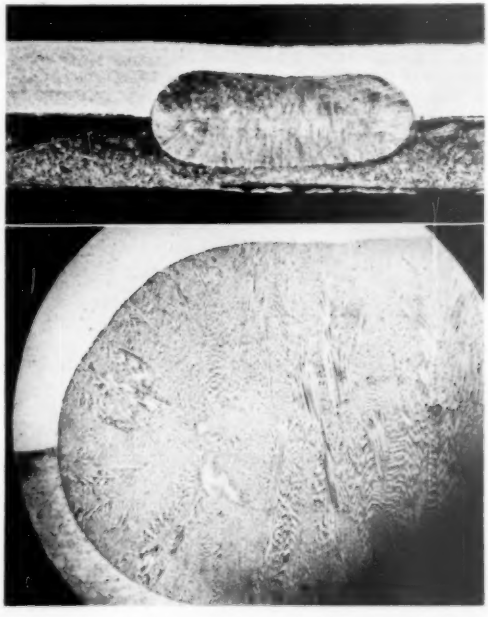

Fig. 2 Macrograph and micrograph of Inconel-stainless-steel combination

sequently, the specimen was immersed in a ferric chloride-hydrochloric acid solution. Table 1 lists the etchants which were employed on the various material combinations.

Table 1

Material combination	*Etchant*
Inconel-stainless steel	Oxalic acid
Inconel-nickel	Oxalic acid
Inconel-Monel	Ferric chloride-hydrochloric acid
Stainless steel-nickel	Oxalic acid
Monel-nickel	Oxalic acid
Inconel-mild steel	Chromic acid
Nickel-mild steel	Nitric acetic acid, then ferric chloride plus hydrochloric acid
Monel-mild steel	Nital, then ferric chloride plus hydrochloric acid
Titanium-titanium	5% Hydrofluoric acid
Mild steel-stainless steel	Nital plus chromic acid
Inconel X	Oxalic acid
Stainless steel-Monel	Oxalic acid

EXPERIMENTAL WORK

Before any actual weld specimens were attempted it was decided to review the constitution diagrams of the various materials with a view to predicting the usability and properties of the welds.

Where the constitution diagram indicated the possibility of obtaining a hard or brittle alloy, a hardness survey was made. In the specific cases of Monel-steel, nickel-steel and stainless steel-steel, microhardness checks were made (see Figs. 6, 8 and 9). On other material combinations such as Inconel-stainless steel, only a superficial hardness test was taken across the weld face.

Table 4—Electrical and Thermal Properties of High-Nickel Alloys

	Nickel	*Inconel*	*Monel*
Electrical resistivity			
Microhms-centimeters at 20° C.	6.84	98.1	48.2
Thermal conductivity			
Cal./cm.²/cm./° C./sec.	0.22	0.036	0.062

The results of the micro and superficial hardness checks are as shown in Table 2.

Chemical analysis of the various materials are as listed in Table 3. The physical properties of all of the alloys were closely scrutinized in order that electrode size, shape and composition and (in the case of direct current) polarity could be anticipated. Because of the wide difference in chemical composition and physical properties of these materials, many problems were anticipated. For example: the electrical resistivity of Inconel is approximately 14 times that of nickel. The heat conductivity of nickel is some seven times that of Inconel (Table 4). Obviously, the weld nugget tends to grow in the Inconel sheet necessitating corrective measures at the electrodes in order to insure proper nugget location. Following are the series of the various combinations with a discussion of each. Generally, the arrangement is in the order of ease of welding. A macrograph at 8 × and a micrograph at 35 × of the weld structure of each combination are included. The welding schedules are as shown in Table 5.

Table 2—Results of Micro and Superficial Hardness Tests

(All readings are converted to Rockwell B)

Material combination	1	2	3	4	5	6	7	8	9	10
				Microhardness						
Monel-steel	64	71	77	76	74	74	67.5	76	72	71
Nickel-steel	60.5	C30	68.5	65	66	65	66	70	67	
Stainless-mild steel	83	79	92	96.5	93.5	87.5	87.5	88	84	82
				Superficial hardness						
Monel-Inconel	69	74	80	80	80	83	83	84	83	..
Nickel-Inconel	59	68	66	72	72	81	80	83	..	..
Steel-Inconel	53	55	72	76	84	80	78	74	..	..
Stainless-Monel	74	74	68	67	80	71	71	75	77	..
Stainless-Inconel	75	73	75	72	72	79	82	81	83	..
Stainless-Nickel	59	64	71	77	77	75	77	79	75	..

Table 3—Chemical Analysis of the Materials Which Were Employed in the Investigation

Material	*"A" Nickel*	*Monel*	*Inconel*	*Mild steel*	*A.I.S.I. 8630*	*Inconel X*	*18–8*
Heat No.	HSP7710	H7711	HNX7709	Unknown	E56840	NX3166X	635788
Carbon	0.03	0.13	0.06	0.12	0.285	0.04	0.06
Manganese	0.22	1.04	0.30	0.55	0.80	0.54	1.62
Iron	0.19	1.85	5.73	Rem	...	6.94	...
Sulphur	0.005	0.005	0.007	0.02	0.019	0.007	0.009
Silicon	0.02	0.18	0.21	0.15	0.29	0.36	0.44
Copper	0.05	29.86	0.11	...	...	0.03	...
Nickel	99.46	66.91	78.94	...	0.55	73.07	11.23
Chromium	...	...	14.62	...	0.50	14.73	17.48
Aluminum	...	...	...	...	...	0.80	...
Titanium	...	...	...	...	...	2.38	...
Columbium	...	...	...	...	...	1.02	0.73
Phosphorus	...	...	...	...	0.010	...	0.024
Molybdenum	...	...	...	...	0.21	...	...

Table 5—Alternating Current Schedules for Dissimilar Materials Combinations

Material combination	*Thickness, in.*	*Electrode force, lb.*	*Weld time, 60~*	*Shear strength, lb.*	*Weld current, amp.*	*Diameter fused in.*	*Minimum weld in.*	*Minimum overlap, in.*	*Electrode size, in.*
Nickel-mild steel	0.063	1500	10	2200	16,200	0.25	1 1/4	5/8	5/16
Nickel-low-alloy steel (8630)	0.063	1500	10	2350	14,500	0.25	1 1/8	5/8	5/16
Nickel-stainless steel	0.063	1800	12	2700	16,000	0.25	1 1/8	5/8	5/16
Nickel-Monel	0.063	2000	12	2900	20,000	0.28	1 1/4	5/8	5/16
Nickel-Inconel	0.063	2500	12	2750	15,500	0.26	1 1/8	5/8	5/16*
Monel-mild steel	0.063	1600	14	2300	17,500	0.25	1 1/4	5/8	5/16
Monel-low-alloy steel (8630)	0.063	1600	14	2450	16,800	0.25	1 1/8	5/8	5/16
Monel-stainless steel	0.063	1800	14	2800	16,000	0.25	1 1/8	5/8	5/16
Monel-Inconel	0.063	2300	14	3000	15,500	0.25	1 1/8	5/8	5/16
Inconel-mild steel	0.063	1600	14	2200	17,000	0.23	1 1/4	5/8	5/16
Inconel-low alloy	0.063	1600	14	2300	16,000	0.25	1 1/8	5/8	5/16
Inconel-stainless steel	0.063	2500	16	2950	14,000	0.28	1 1/8	5/8	5/16
Inconel X-Inconel X	0.063	3400	18	3000	12,000	0.27	1 1/16	9/16	5/16
Titanium-titanium	0.063	800	14	2900	13,000	0.25	1 1/8	11/16	5/16
Titanium-titanium	0.031	600	10	1360	12,000	0.15	5/8	7/8	1/4
Stainless-mild steel	0.063	1600	14	2170	18,000	0.25	1 1/4	5/8	5/16
Stainless-low-alloy steel	0.063	1600	14	2400	17,500	0.26	1 1/8	5/8	5/16

Notes: 1. Electrodes R.W.M.A. Class II 3" Radius of Dome.
* Class III electrode against nickel sheet.

Inconel to Stainless Steel (18–8)

This combination presents the least difficulty (Fig. 2). Inconel and stainless steel present no difficulties as regards nugget size, location and structure. This fabrication is being accomplished on a production basis daily, and has demonstrated satisfactory performance under conditions of high-temperature and high-vibrational stress. Strong ductile welds are readily obtainable through a wide range of machine settings. Tension shear values of 3200 lb. were demonstrated with no evidence of porosity, shrink cracks expulsion or other welding defects. Nugget diameter was 5/16 in.

Nickel to Stainless Steel

With these materials, no difficulties were anticipated as regards the metallurgical forms contained within the weld nugget. Unfortunately, the physical properties of these two materials are such that difficulties will be experienced in achieving proper nugget location. With ordinary electrode combinations, the nugget will lie almost wholly within the stainless-steel sheet. Limited aid can be obtained from the use of a low-conductivity electrode against the nickel sheet, but care must be exercised if sticking or alloying of the electrode to the work is to be avoided.[1, 2] The polarity

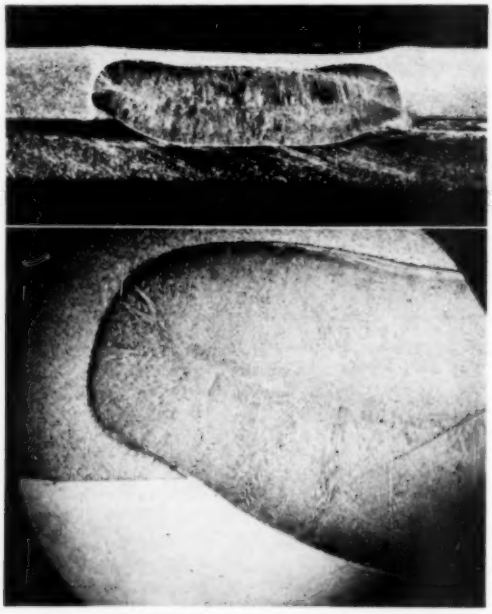

Fig. 3 Macrograph and micrograph nickel-stainless steel (18–8) combination

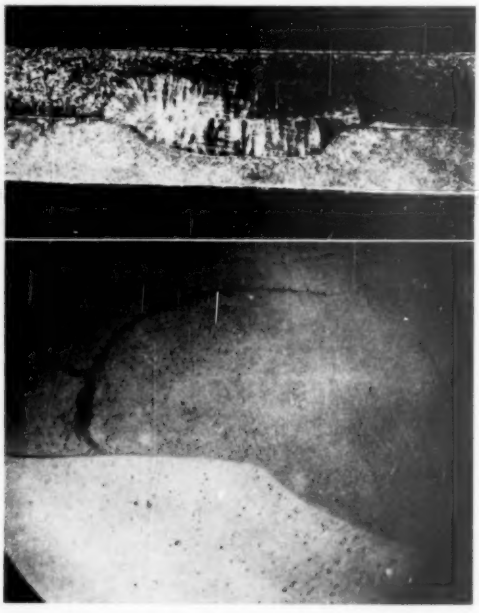

Fig. 4 Macrograph and micrograph nickel-Monel combination. "Coring" is visible at edge of nugget (Ref. 5)

effect of direct current can be employed to advantage in this case. The work may be positioned in the welding machine in such a manner that the nickel touches the positive electrode. Study of the macrograph will show that most of the nugget is contained in the stainless sheet but that penetration into the nickel sheet is about 40% which meets all existing specifications.

Nickel to Monel

The physical properties of Monel and nickel are sufficiently different to cause difficulties from heat balance (Fig. 4). The same reasoning is applicable in this combination as with the nickel-stainless steel. The problem consists mainly in achieving penetration into the nickel sheet. This condition can be alleviated through the use of a Class III electrode against the nickel sheet. It is suggested in the interest of minimizing the alloying of the nickel to the copper-alloy electrode that the bottom of the drilled hole in the electrode be not over $^2/_8$ in. from the face. Metallurgically this material combination should be completely satisfactory since study of the constitution diagrams indicate no brittle or poor alloys will be formed.

Nickel to Inconel

This combination also involves the joining of material of high-electrical resistance to a material of low electrical resistance (Fig. 5). Metallurgically, the material combination is sound. The problem of nugget location was solved as before by using a combination of high- and low-conductivity electrodes plus taking advantage of the polarity effect of the direct current. Examination of the weld nugget shows this to be of unusual shape indicating a faster melting rate of the Inconel possibly aided by the lower heat conductivity of the material. Weld penetration into the nickel is about 40% which is adequate for existing specifications.

Nickel to Mild Steel

Study of the iron-nickel constitution diagrams indicate that there is a possibility of obtaining an air-hardening alloy (Fig. 6). The weld nugget will be a nickel-rich alloy. The area of the spot-weld nugget adjacent to the mild steel should be low in nickel. A microhardness check of this area showed the presence of a hard band at this interface. Table 2 shows the hardness to be Rockwell C30. While this area is hard the alloy is also strong, but not brittle. Tension shear and twist testing indicate ductile weld metal. The tension shear strength averages 2200 lb. The nugget diameter is 0.25 in. Failure occurred in the mild steel. Penetration into the nickel sheet is approximately 50%. The weld is acceptable. The twist test demonstrated 90° which is approximately equal to the results obtained from steel. The welding schedule which was used to obtain the results illustrated in Fig. 6 was as listed in Table 4.

Nickel to NE 8630

NE 8630, because of its medium carbon range, has

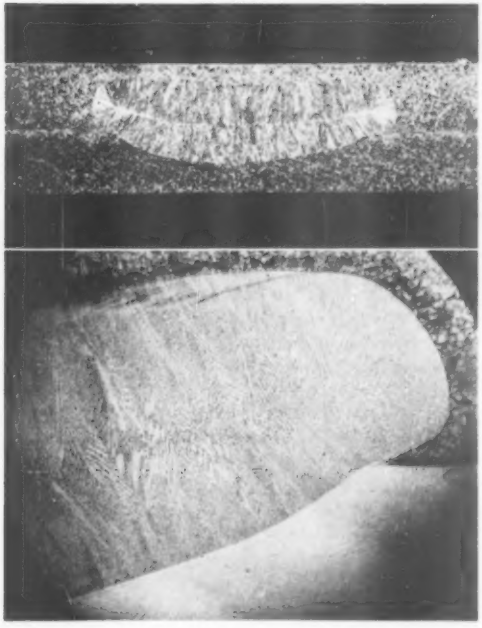

Fig. 5 Macrograph and micrograph nickel-Inconel combination

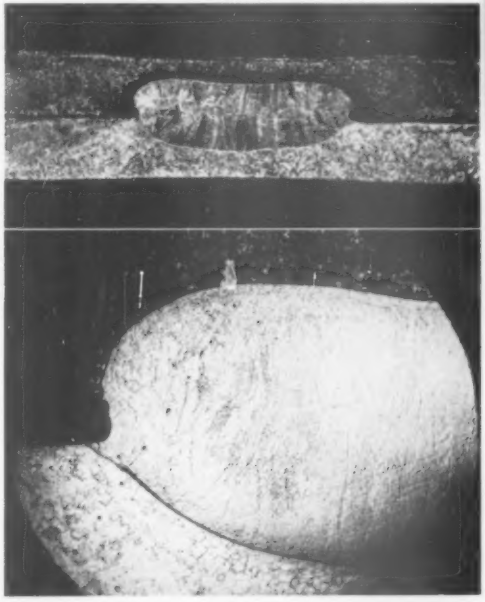

Fig. 6 Macrograph and micrograph of nickel-mild steel combination. Impressions from microhardness survey are visible

some air-hardening tendencies. In routine spot-welding operations, it is essential that a postheat treatment be employed for tempering purposes. Failure to employ a postheat treatment results in extremely brittle welds possibly due to the rapid quench produced by the electrodes. The heat treatment may be performed as part of the spot-welding operation or in a furnace after welding is completed. The degree of hardening of the weld nugget is dependent on the cooling rate. In some cases, especially in heavy gage materials (0.078 in. and thicker), ductile welds may be obtained by keeping the "Hold" time at the lowest possible value thus minimizing the quenching effect of the copper-alloy electrodes. In considering the welding of nickel to NE 8630, it was anticipated, therefore, that the possibility of obtaining welds of excessive hardness was good. The heat conductivity of nickel is good, enhancing the quenching effect. Nickel-iron alloys are hardenable in certain percentage ranges. It was observed, however, that the weld nuggets were strong and ductile, possibly due to the high dilution of the NE 8630 by the nickel.

Inconel to Mild Steel and Low-Alloy Steel

Specimen welds indicated good strength and ductility (Fig. 7). No hardened areas were observed in the hardness test possibly due to the preponderance of nickel in the high-alloy material. Electrode conductivity change was necessary to procure proper nugget location. The low-conductivity electrode was used against the mild-steel sheet. Tension shear strength of 2200 lb. was consistently demonstrated with $^1/_4$-in. nugget diameter. Twist test showed 90°.

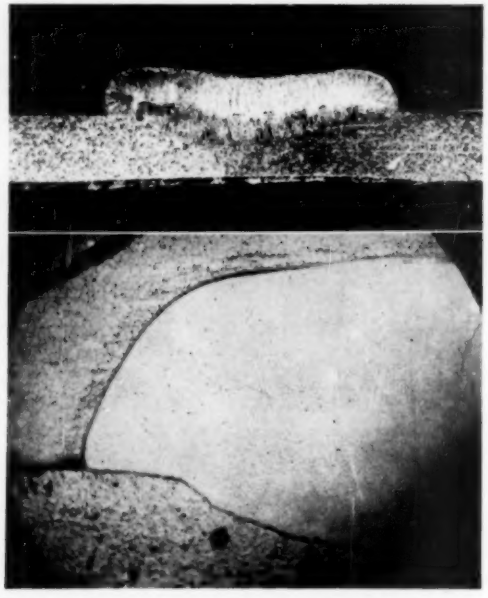

Fig. 7 Macrograph and micrograph Inconel-mild steel combination

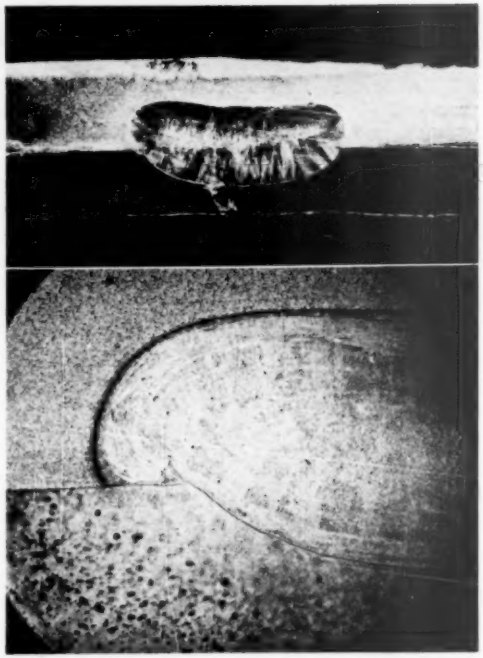

Fig. 8 Macrograph and micrograph stainless steel (18–8) mild steel combination. Microhardness impressions are visible

Stainless to Mild Steel

The combination of stainless (18–8) to mild steel has been successfully spot welded for many years (Fig. 8). Reference to Table 2 indicates that the joint and the parent material are relatively hard. This may be explained on the basis of the rapid quench of the mild steel from the critical temperature. Had the microhardness test been taken in the mild steel away from the heat-affected zone, the reading probably would have shown B60 to B64. Since stainless steel is essentially composed of chromium, nickel and iron, and since it has been shown that the nickel-iron combination in some percentages produces a hardenable alloy as do chromium-iron combinations, it may be assumed that the area of the spot-weld nugget immediately adjacent to the mild steel will contain a degree of hardness. The hardness in this area is Rockwell B96.5, which is considered to be a usable alloy. As previously noted on the nickel-steel combination the alloy is apparently strong as indicated by the type of fracture in the tension shear and twist tests. Should this hardened area be objectionable, presumably it could be alleviated by subsequent heat treatment.

Stainless Steel to Low-Alloy Steel

The ductility of the weld nuggets of this combination was found to be comparable to that of a joint between

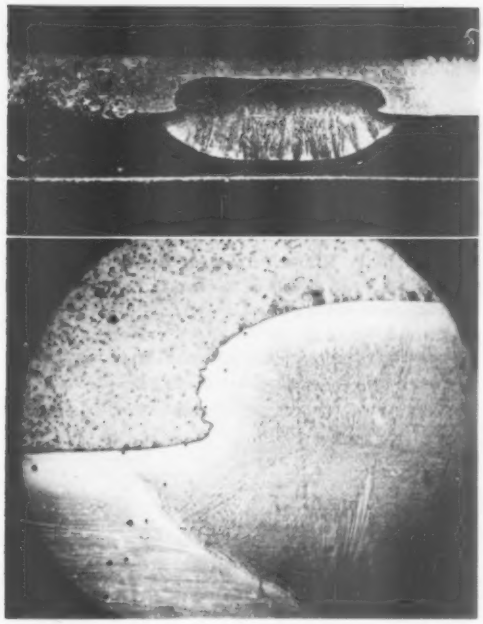

Fig. 9 Macrograph and micrograph Monel-mild steel combination. Microhardness impressions and slight "coring" are visible

two pieces of mild steel. The remarks on the metallurgical aspects of the stainless-mild steel joint are equally applicable to this fabrication. Nugget location was considerably improved over the preceding joint, possibly due to the higher electrical resistivity and the lower heat conductivity of NE 8630. The tension shear test demonstrated measurably higher values indicating the desirability of employing this combination where higher strength than that exhibited by the mild steel-stainless steel combination is required.

Monel to Mild Steel

Difficulties were encountered on this material combination (Figs. 9 and 15). The constitution diagrams show that the presence of 4½% or more of copper in mild steel causes "hot short" cracking. The use of the single-phase alternating-current machine with the bellows locked out resulted in welds containing serious radial cracking (see Fig. 14). By employing the bellows air lock and the slope control device, ductile and sound welds were produced. Similarly through the use of the dry disk rectifier machines with the bellows air lock, sound welds could also be consistently produced. Recommended mill practice indicates that the presence of nickel tends to raise the temperature at which the cracking occurs. Examination of the specimen indicates the presence of a copper-nickel-iron alloy of good corrosion resistance. A twist test indicated weld nugget ductility equivalent to that of mild steel (about 90°). Tension shear testing showed weld failure at 2300 lb. by tearing a nugget. The peculiar nugget shape is probably a function of the cooling rate. It had been previously reported that difficulties were encountered due to cracking in resistance seam welding the Monel-mild steel combination. It was decided to attempt this fabrication on a standard alternating-current seam-welding machine. Sectioned-etched specimens of this weld showed the presence of cracks which extended almost completely through the piece. A low-inertia, dry-disk, rectifier-type seam-welding machine was tried on this fabrication. A macrograph of this weld is shown in Fig. 15. There is no evidence of segregation, checks or cracks in the specimen. A microhardness survey did not disclose the presence of any hard or brittle alloys.

The seam-welding schedule which was employed on this material combination was: Electrode force 1200 lbs.; Electrode, Class 3, ½-in. face x 10 in. diameter x 10 in. radius; time cycle 114 millisec. "on," 152 millisec. "off" corresponding to 6.82 cycles "on" and 9.10 cycles "off" (based on 60 cycle waves), at 10 spots per inch. Current was approximately 12,000 amp. Speed was approximately 23 in. per minute.

Monel to NE 8630

As previously noted, combinations involving 8630 material was questioned due to the air-hardening tendencies of chrome-molybdenum steel. It appears that the degree of dilution by the nickel-copper alloy is sufficiently great to minimize any hardening tendencies. The technique and equipment was the same as that employed on the Monel-mild steel combination. No

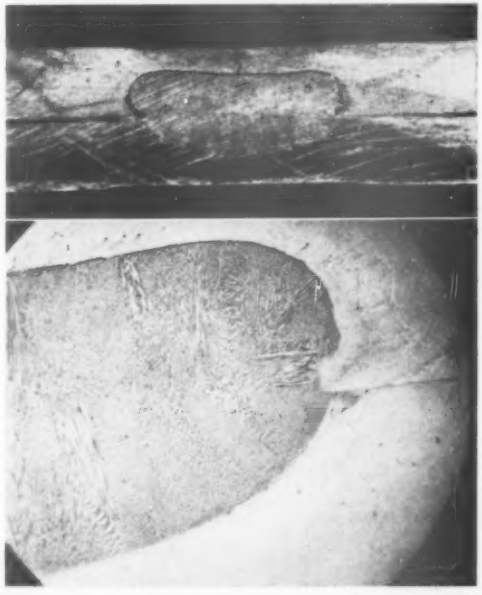

Fig. 10 Macrograph and micrograph Monel-stainless steel combination

heat balance problems exist. Study of the weld nuggets under high magnification show the presence of a nickel-rich constituent. No hardened areas were disclosed. Ductility of the weld metal as indicated by the twist test was excellent. Over 90° was demonstrated before complete failure. Penetration into the 8630 sheet is 40%. Tension shear value was 2300 lb. with 1/4 in. nugget diameter.

Monel to Stainless Steel

This material combination was approached with extreme caution because a previous attempt at fusion welding this combination had resulted in extreme cracking difficulties (Fig. 10). It has been shown: (*a*) that the presence of copper in steel in certain percentages is a cause of "hot short" cracking; (*b*) that the presence of nickel in steel in some percentages results in a hardenable alloy as does the presence of chromium. Attempts to spot weld this material combination over standard alternating-current equipment resulted in severe radial cracking. However, through the use of the newer type three-phase, direct-current equipment, sound welds were consistently produced. No difficulties due to nugget location or heat balance were encountered. Microscopic examination of the weld structure did not disclose any unusual metallurgical forms. The hardness traverse did not show any hardened areas or brittle constituents. The maximum hardness (Table 2) was found to be Rockewll B80. Ductility as indicated qualitatively by the amount of plastic flow during the tension shear test was excellent. The tension shear value was 2800 lb. with failure occurring in the parent material. The twist test demonstrated over 100° before complete failure.

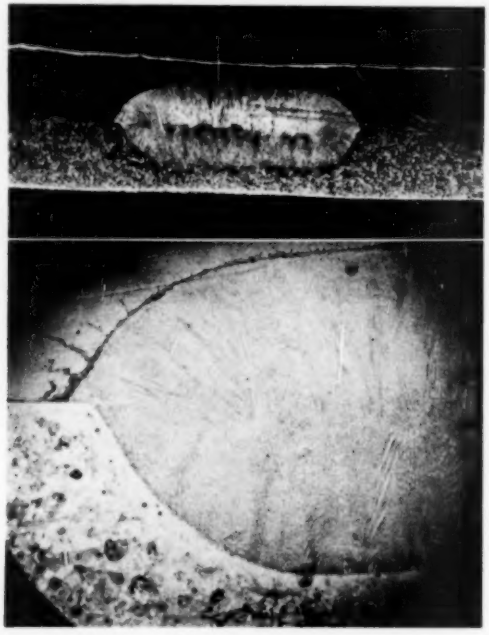

Fig. 11 Macrograph and micrograph Monel-Inconel combination

Monel to Inconel

No difficulties were experienced with weld nugget location (Fig. 11). Weld nuggets are of good ductility although cracking difficulties were anticipated due to the chromium content of the Inconel being alloyed with the copper in the Monel. Presumably, nickel is present in sufficient quantities to maintain the copper and chromium in solution so that no cracking difficulties are experienced. Strong ductile welds are obtainable on this material combination. A hardness survey did not indicate the presence of any hard bands or areas. Twist test demonstrated 120°. Tension shear test showed 2760 lb. Penetration was approximately 60% in each material.

Inconel X to Inconel X

Inconel X may be readily spot welded using schedules similar to those employed for Inconel (Fig. 12). The material shows definite sparking tendencies at the electrodes. For this reason the material should be buffed or polished before welding is attempted. Higher than normal electrode force aids in controlling the expulsion tendencies. It has been observed that the material hardens as a result of a fast cooling rate. Spot welds in Inconel X are usable in the as-welded

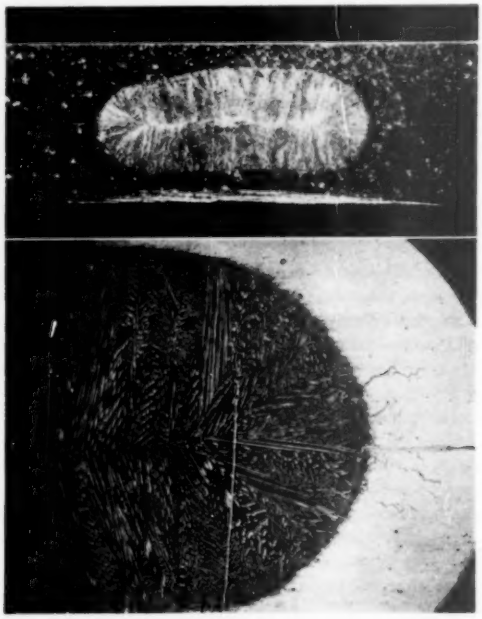

Fig. 12 Macrograph and micrograph of spot weld in Inconel X. "Coring" at edges of nugget is rare in Inconel. In this material, coring is usually associated with high-electrode force

condition in gages of 0.021 and heavier. However, on a specific application involving the joining of two pieces of 0.010-in. thick material, it was necessary to insert a 0.002 Inconel shim at the faying surface in order to obtain sufficient weld ductility to form the part.

Usually such measures are unnecessary where a suitable heat treatment may be employed following the welding operation. The part in question had an extremely large volume-to-weight ratio which made subsequent heat treatment impractical. Through the use of the Inconel foil as shim stock, it was possible to raise the elongation of the Inconel X in the "as-welded" condition from 4 to 28%, thus enabling the following forming operations to be performed. A degree of coring has been noted at the edges of the weld nugget.[3]

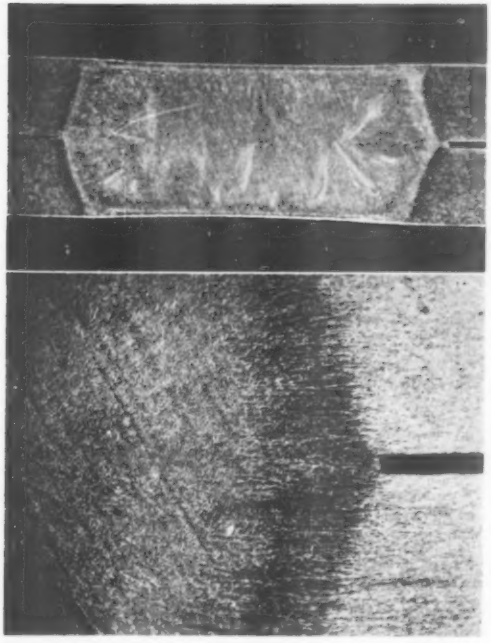

Fig. 13 Micrographs of spot weld in titanium. Edge of spot-weld nugget which shows the heat-affected zone in which solid phase welding occurred

Titanium

The spot-welding schedules for titanium are included as a matter of general interest. For this resistance welding investigation, coupons 0.031- x $^5/_8$- x 3 in and 0.063- x $^3/_4$- x 4 in. were cut from the sheet stock. Electrodes were of R.W.M.A. Class II material; $^5/_{16}$ in. diameter with domed radius of 3 in. Welding schedules which will produce satisfactory results are as shown in Table 4.

The schedules apparently are not critical; for example, on the 0.063-in. material, time was varied from 6 to 18 cycles. In every case failure of the specimen occurred in the heat-affected zone at the periphery of the weld. Tension shear strength varied only slightly when the material was welded using a short time cycle.

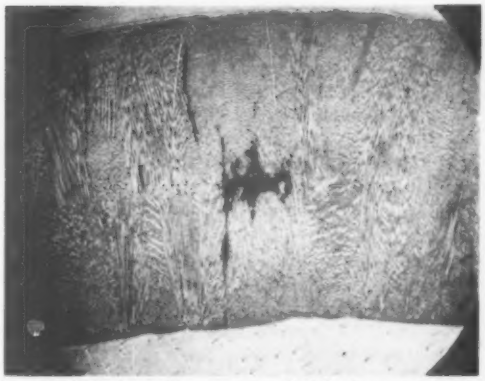

Fig. 14 Radial cracking associated with the use of high-inertia equipment on Monel-mild steel combination

In an attempt to improve the ductility of welded material, five specimens of 0.031-in. material, using the welding schedule above, were made and subsequently heat treated at 1200° F. for 1 hr. Tension shear strength was reduced to 1300 lb. There was a noticeable improvement in ductility as indicated by the tension shear tests.

The results of the spot-welding study are similar to those found in the Bureau of Mines investigation[4] although not truly comparable since their work was conducted with nonstandard electrodes.

The penetration of weld is approximately 70% of the cross section as represented by the inner nugget of fused metal. The outer zone shown in Fig. 13 represents the heat-affected area which apparently was soft enough during the welding cycle for solid-phase welding to occur. In the shear tests the solid-phase weld parted readily and final fracture followed the outer contour of the inner fused zone.

SUMMARY

The welding schedules required to produce acceptable resistance welds in twelve dissimilar material combinations have been investigated. The results indicate that all of these material combinations can be satisfactorily welded but the necessary schedules were found to fall into three general categories.

The first classification includes those materials or combinations which can be welded satisfactorily on the

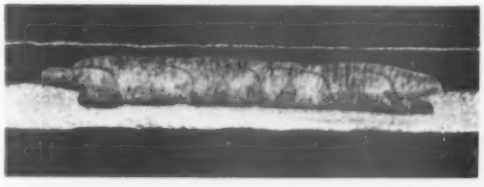

Fig. 15 Macrograph of seam weld in Monel-mild steel combination. Diagonally cut specimen

older type of synchronous control spot-weld equipment without encountering serious physical or metallurgical problems. These combinations include: Inconel to stainless steel; nickel to stainless steel; nickel to Monel and nickel to Inconel.

In the second classification are those combinations which require equipment of the low-inertia head type combined with synchronous control. In this classification are such material combinations as: nickel to mild and low-alloy steel; Inconel to mild and low-alloy steel and stainless steel to mild and low-alloy steel.

The third classification includes those materials which require the use of sensitive welding schedules plus advanced design equipment such as that employing the combination of low-inertia heads plus the low-wave front secondary characteristics. These are Monel to mild steel, Monel to stainless steel and Monel to Inconel.

The criteria for the acceptance of the welds were the macro etch test, the tension shear test, the twist test, the hardness test and microscopic examination.

That further research and development must be undertaken is evident. The fatigue properties of the welded joints have not yet been investigated. Checks for electrolysis between the metals being joined remain to be taken. Performance of the spot welds at elevated temperatures has not been studied. The foregoing is not intended to discourage the use of these material combinations but rather to point up the necessity of further study for the specific application. Some of the material combinations such as Inconel-stainless steel and stainless steel-mild steel have proved to be satisfactory under conditions of high-temperature and high-vibrational stress. It has been shown that the nickel-steel combination will have a hard (Rockwell C30) band at the juncture of the weld nugget and the mild steel. While the alloy in this area is hard, it is also strong and is not necessarily brittle. For routine applications this weld is satisfactory as indicated by the type of fracture in tension shear and twist testing. The combination of Monel-mild steel can be successfully spot and seam welded without cracking or other welding defects if presently available equipment of advanced design is provided.

Welds between such materials as nickel-Monel, nickel-Inconel and nickel-stainless steel appear to offer few metallurgical difficulties although nugget location becomes a problem due to the relative electrical resistivity and heat conductivity of the alloys. The use of the proper electrode sizes, compositions, and the employment of the proper welding technique will usually minimize these problems.

It should not be inferred that the schedules shown in Table 5 cannot be changed in the interest of better quality welding or because of specialized applications. These are intended only as a starting point in the adjustment of the welding machine. The actual production application will determine the optimum schedule.

ACKNOWLEDGMENT

The generosity of the International Nickel Co. in furnishing the materials which were used in the experiments is gratefully acknowledged. For his many helpful suggestions and metallurgical efforts, particular credit is extended to J. F. Tyrell, Research Metallurgist, Solar Aircraft Co. To A. L. Bennett and S. P. Weston of the Solar Research Staff go sincere thanks for their capable assistance in testing and photography.

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Corrosion of Molybdenum-Bearing Stainless-Steel Weld Metals

Corrosion of as-welded stainless-steel specimens depends upon the type and location of the carbide and sigma precipitates. Effect of ferrite and heat treatments is indicated for each type

by Anton L. Schaeffler and R. David Thomas, Jr.

Abstract

Eleven compositions of weld metal within the range of analysis of Types 316, 317, 318 (316Cb) and extra low carbon 316 have been subjected to boiling 65% nitric acid and to boiling copper sulphate-sulphuric acid. Each composition was tested in the as-welded state and in four conditions of heat treatment. The compositions were adjusted by varying the chromium and nickel contents in such a manner as to produce microstructures with ferrite varying from 0 to 8%.

In boiling nitric acid, the corrosion rates were consistently good only after a quench-annealing (1950° F.) heat treatment. Intergranular carbide precipitation in the Types 316 and 317 accounts for the high rates observed in some specimens treated at 1200 and 1300° F. Since the columbium-bearing Type 318 and the 0.03% carbon Type 316 also showed high rates, the presence of an intergranular sigma precipitate is postulated. The duplex structures containing 6% or more ferrite are resistant to intergranular attack. At 1550° F. carbides and sigma become agglomerated and the nitric acid rates are substantially improved. During heat treatments at 1300 or 1550° F., any ferrite which may be present transforms to sigma which lowers the ductility of the weld metal, but this type of sigma is relatively unattacked by nitric acid. In the as-welded condition the results vary considerably depending upon the type and location of the carbide and sigma precipitates.

In 500-hr. tests in boiling copper sulphate-sulphuric acid, corrosion is evident only in those specimens containing intergranular carbides. The Types 318 and extra-low carbon 316 show no evidence of attack in these tests, and only the Types 316 and 317 specimens containing less than 4% ferrite are attacked.

Nitric acid tests of welded joints reveal no additional information that is not found in the specimens obtained from all-weld-metal pads. The interpretation of corrosion data from joint specimens is largely qualitative.

INTRODUCTION

CORROSION resistance of stainless steels has received an enormous amount of attention during the past 25 yrs. The corrosion problems resulting from the welding operations have been reported frequently, especially the subject of intergranular attack in a zone of the plate near the weld. Comparatively little work has been done on the corrosion resistance of weld metal.

Most of the published information on the corrosion resistance of welds has failed to give adequate consideration to the metallurgy of the deposited weld metal. If welded joints were subjected to test, it was usually difficult to establish the relative amount of attack in the various areas—the weld metal, the heat-affected zone and the unaffected base metal. Data on the corrosion rates for weld metal alone are extremely scarce and therefore the work covered in this paper is intended to fill an urgent need.

Stainless steels of the so-called 18-8 type are supplied in wrought form in a composition which is fully austenitic or in what is termed a "balanced" structure. Most of these compositions in cast- or weld-metal form show a small percentage of ferrite in the microstructure. The presence of ferrite has been found to be beneficial from the standpoint of the resistance of the weld metal to hot tears and cracks, and therefore there has been a strong tendency to establish compositions which would produce up to 10% ferrite in the structures of the 18-8 types of corrosion resisting weld metals.

In boiling nitric acid corrosion tests, Ellinger and Bibber[1] showed in 1937 that the presence of ferrite in 18-8 welds was not detrimental. This has been confirmed frequently by tests in the authors' laboratory, not only for 18-8, but also for the columbium stabilized grades over a wide range of compositions. This did not seem to be true, however, in the molybdenum grades, especially in the as-welded condition. The results which were obtained appeared to vary con-

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Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

siderably with the particular lot or heat analysis. It was decided, therefore, that a more systematic approach to the problem was needed.

To provide data which will be useful to industry, the program was arranged to include a wide variety of weld metal compositions within the ranges for Types 316, 317, 318 and extra low carbon 316 (0.03% max., referred to as 316*elc*). Inasmuch as corrosion resisting vessels are sometimes placed in service with no heat treatment after welding, but more often in critical service applications with one of a variety of postheat treatments, the more common heat-treating practices were therefore applied to each of the compositions.

The evaluation of corrosion resistance of metals for a wide variety of exposure conditions is an enormous task. In this program the weld metals have been subjected to the two common laboratory tests for stainless steels, the boiling 65% nitric acid test (referred to as the Huey test) and the boiling copper sulphate-sulphuric acid test (referred to as the Aborn test). The authors are well aware of the limitations of accelerated laboratory corrosion tests and will readily agree that conclusions based on these tests may not be confirmed in actual service. Nevertheless, the data obtained will undoubtedly form a starting point for subsequent work now being contemplated wherein specimens will be evaluated both by the accelerated laboratory tests and by actual service media.

PROCEDURE

Approximately 50 lb. each of 11 compositions of $^5/_{32}$-in. diameter electrodes were prepared using a standard lime-type coating (no titania) conforming to A.W.S. classification Exxx-15. Within each grade, the same heat of core wire was used and the weld metal composition was adjusted by coating additions of ferro alloys. The aim analyses are shown as follows:

Type	*No.*	*Cr*	*Ni*	*Mo*	*Other*
316	5170	18	14	2	...
	5171	18	13	2	...
	5172	18	12	2	...
	5319	18	11	2	...
	5173	20	11	2	...
317	5531	19	17	3	...
	5532	19	14	3	...
	5533	21	14	3	...
318	5317	18	14	2	Cb 0.8
	5318	18	12	2	Cb 0.8
316*elc*	5610	18	14	2	C 0.035 max.

In the Type 316 series the first four compositions vary in nickel content within the commercial range for E 316 electrodes, the highest nickel contents having no ferrite and the lowest about 5% ferrite. By adding chromium to the lowest nickel content, the ferrite content is increased to about 8%. For the Type 317 series the middle composition represents the typical analysis for this grade and has about 3% ferrite. By adding nickel a fully austenitic weld deposit is produced, and by adding chromium the ferrite content is increased to about 8%. Of the two compositions prepared in Type 318, the higher nickel contains no ferrite and the lower nickel contains about 3% ferrite. For Type 316*elc*, it was not possible to alter the composition of the weld metal because alloy additions through the coating caused an unacceptable increase in carbon content. Heats of core wire having wide variations in chromium and nickel content with remaining elements constant were not available, and therefore the program was limited to a single composition.

Standard weld-metal analysis pads and tensile specimens were prepared following the procedure outlined in "Tentative Specifications for Corrosion Resisting Chromium and Chromium-Nickel Steel Welding Electrodes" (A.S.T.M. Designation: A298–48T; A.W.S. Designation: A5.4–48T). Having ascertained that the analysis was reasonably close to the original aim, the weld pads for the corrosion specimens were prepared as described below and the top layers machined for chemical analysis. In this manner, two complete analyses of weld metal were obtained for each composition, and the average of these two analyses is reported. The analyses and tensile data are shown in Tables 1 and 2.

The pads of weld metal for securing the all-weld-metal corrosion specimens were prepared by depositing successive layers of weld metal on a 1-in. thick stainless plate to obtain a pad measuring $2^1/_2$ by 6 by $^5/_8$ in. high. For the 316*elc* deposit, the height was increased to 1 in. in order to avoid any possible carbon contamination from the higher carbon-base metal. The welding current was 125–130 amp., the arc length was 22–24 v. and the interpass temperature did not exceed 150° F.

Ten corrosion specimens were machined from each pad, five for the Huey test measuring 2 by $^1/_2$ by $^1/_4$ in. and five for the Aborn test measuring $2^3/_8$ by $^3/_{16}$ in. by $^3/_{16}$ in. (dimensions of the specimens relative to the original pad dimensions are shown in the same order as listed above—i.e., the 2- and $2^3/_8$-in. specimen lengths corresponding to the width of the pad, etc.). All heat treatments were conducted before final machining when the specimens were approximately $^1/_8$ in. larger than the finished dimensions.

The specimens from each pad were marked *W*, *R*, *T*, *N* and *N*+*S*, corresponding to the following conditions of postheat treatment:

W—As-welded.

R—Stress relieved at 1300 ± 40° F., held 2 hr. and cooled in still air.

T—Stabilized at 1550 ± 35° F., held 2 hr. and cooled in still air.

N—Annealed at 1950° F., for $^1/_2$ hr. and quenched in water.

N+*S*—Annealed and quenched as described above and then sensitized by holding at 1200° F. for 2 hr. and cooling in still air.

In all cases except those calling for the 1950° treat-

ment, the specimen was placed in a cold furnace and raised to the desired temperature at a rate shown in Fig. 1.

In order to correlate the corrosion data obtained on the weld-pad specimens with those obtained from welded joints in similar steels, six of the electrode compositions were selected for preparing butt welds in the base metals, whose compositions are shown in Table 1. The details of the welding procedures used are shown in Fig. 2. The location of corrosion specimens and heat treatments applied are shown in Fig. 3.

The Huey tests were carried out in accordance with "Tentative Recommended Practice for Boiling Nitric Acid Test for Corrosion-Resisting Steels" (A.S.T.M. Designation: A262–44T). The average corrosion rates are shown in Table 3 for the all-weld-metal specimens and in Table 4 for the joint specimens.

The solution used for the Aborn tests consisted of 47 cc. concentrated sulphuric acid and 13 gm. crystalline copper sulphate ($CuSO_4 \cdot 5H_2O$) per liter of water. The specimens were polished to 120 grit finish and then were boiled for 500 hr. in the solution. Specimens were

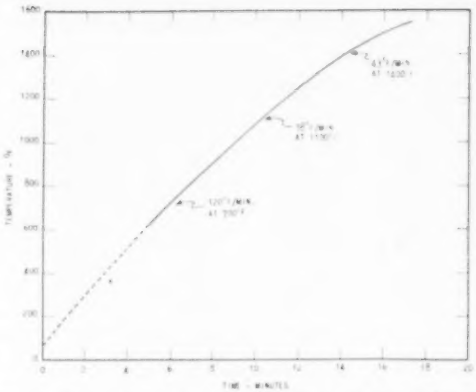


Fig. 1. Curve showing rate of heating of sentry globar furnace in which specimens were heat treated

evaluated by bending around a $^3/_{16}$-in. diameter pin and observing whether the surface revealed grain boundary separations using a 10-power magnifier when necessary. These observations are tabulated in Table 5. The

Table 1—Chemical Composition of Materials

No.	*Type*	*C*	*Mn*	*Si*	*S*	*P*	*Cr*	*Ni*	*Mo*	*Cb*	*N*	*% ferrite*
					Core wires							
5170*W*	316*	0.054	1.56	0.50	0.024	0.025	18.73	11.92	2.30	...	...	...
5531*W*	317	0.058	1.85	0.54	0.019	0.020	20.28	13.80	3.79	...	0.053	...
5610*W*	316*elc*	0.028	2.30	0.49	0.016	0.008	19.21	13.60	2.29	...	...	...
					Weld metals							
5170	316	0.059	1.45	0.46	0.012	0.028	17.78	14.23	2.23	...	0.059	0
5171	316	0.060	1.48	0.45	0.012	0.025	18.10	13.24	2.26	...	0.056	0
5172	316	0.065	1.56	0.43	0.013	0.026	18.22	12.05	2.25	...	0.050	0–2
5319	316	0.064	1.27	0.47	0.010	0.026	18.89	10.94	2.12	...	0.041	4–7
5173	316	0.062	1.48	0.48	0.010	0.025	20.55	11.48	2.21	...	0.058	6–9
5531	317	0.056	1.68	0.50	0.011	0.024	18.90	17.28	3.41	...	0.061	0
5532	317	0.061	1.70	0.44	0.008	0.025	19.71	13.90	3.42	...	0.067	2–4
5533	317	0.063	1.70	0.48	0.011	0.028	21.46	13.52	3.63	...	0.060	6–9
5317	318	0.062	1.55	0.64	0.011	0.025	17.49	14.28	2.15	0.80	0.041	0
5318	318*	0.067	1.56	0.56	0.012	0.026	18.02	11.87	2.16	0.80	0.064	0–6
5610	316*elc*	0.034	1.55	0.14	0.011	0.011	18.41	13.97	2.30	...	0.043	0–2
					Base metals							
...	316	0.065	1.90	0.30	0.013	0.023	17.98	12.00	2.15	...	0.032	...
...	317	0.053	1.73	0.47	0.013	0.025	18.06	13.35	3.06	...	0.027	...
...	318	0.046	2.01	0.75	0.017	0.023	17.75	13.84	2.24	0.86	0.024	...
...	316*elc*	0.023	1.47	0.57	0.015	0.027	17.06	13.62	2.40	...	0.024	...

* Type 316 core wire was used for the 318 weld deposits as well as the 316 deposits.

Table 2—All-Weld-Metal Tensile Tests, As-Welded

Number	*Type*	*Yield* strength, ksi.*	*Tensile strength, ksi.*	*Elongation in 2 in., %*	*Reduction of area, %*	*Fissures†*	*Observed % ferrite*
5170	316	55	81	35	43	8–*B*	0
5171	316	56	81	34	40	4–*B*	0
5172	316	57	82	36	54	0	0–2
5319	316	64	88	37	49	0	4–7
5173	316	62	88	36	51	0	6–9
5531	317	56	85	40	54	1–*N*	0
5532	317	68	96	30	36	0	2–4
5533	317	70	96	31	28	0	6–9
5317	318	63	84	18	20	24–*B*	0
5318	318	66	88	35	46	3–*N*	0–6
5610	316*elc*	54	84	34	50	1–*N*	0–2

* Yield strength by dividers. Yield and tensile strengths reported in kips per square inch (1000 psi.).
† Number of fissures observed on cylindrical surface of specimen. *B* designates that break occurred at a fissure. *N* designates that break did not occur at a fissure.

Table 3—Corrosion Rates of All-Weld-Metal Specimens in Boiling 65% Nitric Acid

			Inches penetration per month—average of five 48-hr. periods				
Electrode No.	*Ferrite, % as-welded*	*Type*	*W As-welded*	*R Stress relieved, 1300° F.*	*T Stabilized, 1550° F.*	*N Annealed, 1950° F*	*N + S Annealed + sensitized, 1200° F.*
5170	0	316	0.0012	0.0260	0.0048	0.0009	0.0139
5171	0	316	0.0008	0.0365	0.0020	0.0007	0.0139
5172	0–2	316	0.0128	0.124	0.0025	0.0008	0.0287
5319	4–7	316	0.0022	0.0022	0.0010	0.0008	0.0335
5173	6–9	316	0.0024	0.0016	0.0007	0.0006	0.088
5531	0	317	0.0011	0.0387	0.0018	0.0009	0.0300
5532	2–4	317	0.0442	0.103	0.0024	0.0009	0.0265
5533	6–9	317	0.0224	0.0021	0.0009	0.0007	0.0495
5317	0	318	0.0064	0.0186	0.0032	0.0013	0.0039
5318	0–6	318	0.0060	0.0066	0.0014	0.0010	0.0139
5610	0–2	316*elc*	0.0007	0.0027	0.0007	0.0004	0.0029

bend elongations are estimated from the radius of curvature of the bend specimens.*

After completion of all tests, the Huey and Aborn specimens were subjected to a magnetic test principally to observe the influence of heat treatment upon the ferrite phase. An Alnico magnet measuring about 1/4 in. thick and about 1 1/4 in. across the yoke was suspended from a string 23 in. long. The specimen was held against the side of the magnet and was pulled away from the vertical position along an arc. The distance in inches from the vertical at which the magnet broke away from the specimen was considered to be the magnetic rating of the specimen. It is believed that the magnet was able to detect less than 1% ferrite, which would be rated 0+ (slight movement of the magnet). Though the method is admittedly crude, specimens of the same size are believed to give a quantitative rating. The magnetic ratings of the corrosion and tensile specimens are shown in Table 6.

Discussion

A study of corrosion resistance based upon accelerated laboratory corrosion tests will have little significance if the study does not reveal the mechanism of the corrosive attack. The analysis of the data collected in this program permits a few generalizations which should be useful in later studies of corrosion of welds under service conditions. It should be emphasized that the evaluation methods, namely boiling 65% nitric acid and the copper sulphate-sulphuric acid solutions, were developed primarily for revealing susceptibility to intergranular corrosion. In recent years it has become evident that the copper sulphate-sulphuric acid attack is limited to intergranular corrosion caused by the precipitation of carbides in the grain boundaries, whereas nitric acid will attack not only the grain boundaries in which carbides are precipitated but also those having an extremely fine precipitate of what is believed to be sigma.[3–4] Extremely low-carbon alloys heat treated in a manner which is known to precipitate sigma will show high nitric acid corrosion rates unless sufficiently high temperature is used, permitting the precipitate to agglomerate.

In alloys containing delta ferrite in a matrix of austenite, the secondary delta phase shows little, if any, attack by nitric acid excepting in steels containing molybdenum. This observation leads to the strong suspicion that in two-phase molybdenum alloys containing delta ferrite incipient transformation of the ferrite boundaries to sigma accounts for the high-corrosion rates.[5, 6] Unfortunately the precipitated particles, presumably occurring first at the boundaries of the ferrite pools, are so fine as to be undetectable by the usual metallographic techniques.

* Assuming the neutral axis is a plane midway between the tension and compression surfaces of the bend specimen and no deformation occurs therein, the elongation may be determined from the relation $T/2R_n$, where T is the thickness and R_n is the radius of curvature of the neutral axis. This may be seen by observing that the length of the tension fiber less the length of the neutral axis is in direct proportion to the difference in radius of curvature of the corresponding planes. Thus elongation =

$$\frac{R_t - R_n}{R_n} = \frac{1}{R_n}\frac{T}{2}$$

where R_t is the radius of curvature of the tension surface.

Table 4—Corrosion Rates of Plates and Butt Welds in Boiling 65% Nitric Acid

			Inches penetration per month—average of five 48-hr. periods						
				As-Welded		*Stress relieved, 1300° F.*		*Stabilized 1550° F.*	
Electrode No.	*Ferrite, % as-welded*	*Type*	*PA As-received, plate*	*WA Weld metal only*	*WB Weld + 1/16-in. plate*	*W Welded joint*	*PR Plate*	*R Welded joint*	*PT Plate*	*T Welded joint*
5170	0	316	....	0.0014	0.0009	0.0007	....	0.105	....	0.0211
5173	6–9	316	0.0006	0.0016	0.0010	0.0008	0.110	0.092	0.0139	0.0121
5531	0	317	....	0.0012	0.0012	0.0012	....	0.155	....	0.0319
5533	6–9	317	0.0011	0.0334	0.0069	0.0038	0.142	0.159	0.0212	0.0190
5318	0–6	318	0.0015	0.0029	0.0035	0.0023	0.0174	0.0255	0.0049	0.0043
5610	0–2	316*elc*	....	0.0007	0.0009	0.0009	....	0.160	....	0.0014
5318*	0–6	316*elc*	0.0009	0.0031	0.0025	0.0016	0.174	0.159	0.0014	0.0021

* The 318 electrode is used for welding 316*elc* plate. In all other cases the plate type and electrode type are the same.

Type 316 All-Weld-Metal Specimens

In this group a wide variation in composition was obtained from five lots varying in as-deposited ferrite content from zero to approximately 8%. Plotting the average corrosion rates in boiling 65% nitric acid as a function of the observed as-welded ferrite content, the effect of each of the five heat treatments upon the ferrite may be observed, as shown in Fig. 4.

In the as-welded condition the peak occurring in the specimens containing a low percentage of ferrite would probably be considered a "freak" were it not that the same peak also occurs in the Type 317 specimens. Furthermore the rates are not unexpected based upon previous data from commercial heats of Type 316 weld metal. Metallographic examination of the as-welded specimens shows that in duplex alloys the attack occurs around the ferrite patches and in fully austenitic alloys the attack is intergranular (Fig. 5). In multipass welding the heat effects caused by each layer upon the layer below cause metallurgical changes to occur. Carbide precipitation is known to occur in

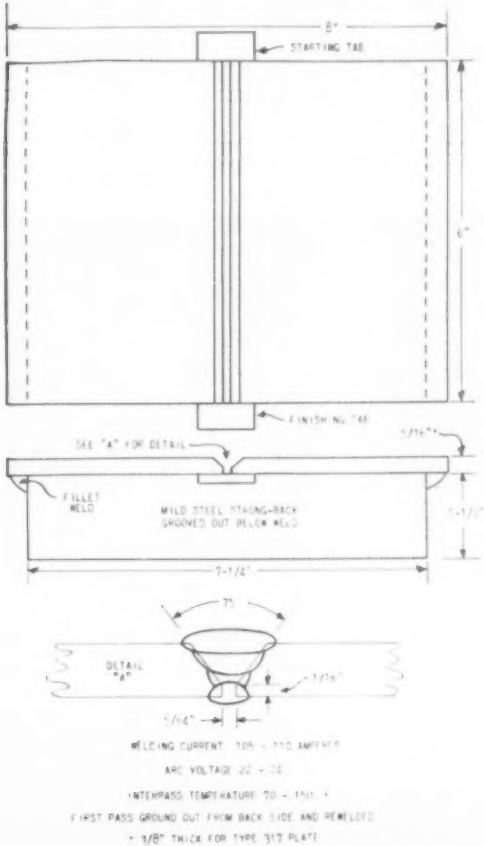


Fig. 2 Joint preparation and welding data

Table 5—Observations of Aborn Tests of All-Weld-Metal Specimens

		W			R			T			N			N + S		
		As-welded			Stress-relieved, 1300° F.			Stabilized, 1550° F.			Annealed, 1950° F.			Annealed + sensitized, 1200° F.		
No.	Ferrite, % As-welded	Type	Intgr. att.	Bend angle	Bend elong., %	Fissures	Intgr. att.	Bend angle	Bend elong., %	Fissures	Intgr. att.	Bend angle	Bend elong., %	Fissures	Intgr. att.	Bend angle	Bend elong., %	Fissures
5170	0	316		180	46			<180	<46	X		180	46			180	46	
5171	0	316		<180	46			<180	<41			<180	<53	X	X	<180	<41	X
5172	0–2	316		180	46			<180	<53			<180	<53			<180	<53	X
5319	4–7	316		180	53			180	46			180	46			<180	<41	
5173	6–9	316		180	53			120	35			105	31			180	53	
5531	0	317		115	29	X	XX	0	0			<180	<61	X		180	53	X
5532	2–4	317		170	51			140	20			90	14			180	46	
5533	6–9	317		170	31			60	7			60	6			170	46	
5317	0	318		130	46	X		105	34	X		95	37	X		180	53	
5318	0–6	318		180	53			145	37			90	27			180	53	
5610	0–2	316*elc*		<180	<53	X		<180	<53	X		<180	<53	X		170	41	X		180	53	

Note: /—Fissures under 1/64-in. or slight intergranular attack. X—Fissures in excess of 1/64-in. or severe intergranular attack. XX—Very severe intergranular attack. 180—Bent flat; no major defect. <180—Bent flat; contained major defect at this bend angle. 170—Not bent flat; contained major defect at this bend angle.

Table 6—Magnetic Rating of All-Weld-Metal Test Specimens

Electrode No.	Type	Ferrite, % as-welded	As-welded			Stress relieved, 1300° F.		Stabilized, 1550° F.		Annealed, 1950° F.		Annealed + sensitized	
			Tensile bars*	Huey test	Aborn test	Huey test	Aborn test	Huey test	Aborn test	Huey test	Aborn test	Huey test	Aborn test
5170	316	0	0	0	0	0	0	0	0	0	0	0	0
5171	316	0	0+	0+	0+	0	0+	0	Missing	0	0	0	0
5172	316	0–2	1	4	3	0+	0+	0+	0+	0+	0+	0+	0+
5319	316	4–7	12+	10	9	3	2	1	1	1	1	0+	0+
5173	316	6–9	12+	12+	12	4	3	1	1	9	9	2	2
5531	317	0	0	0	0	0	0	0	0	0	0	0	0
5532	317	2–4	10	10	7	0	0	0	0	0	0	0	0
5533	317	6–9	12+	12+	12+	0+	0	0	0	2	2	0+	1
5317	318	0	0	0	0	0	0	0	0	0	0	0	0
5318	318	0–6	4	4	3	0+	0+	0	0	1	1	0+	0+
5310	316*lc*	0–2	2	3	1	0	0	0	0	0	0	0	0

* Taken on threaded end.

certain zones and the formation of sigma may also take place. When substantial amounts of ferrite are present, intergranular precipitation apparently does not occur during the heat cycles generated by welding, but such precipitates as are formed are associated with the ferrite patches. In fully austenitic alloys, all precipitation occurs in the grain boundaries. Apparently intergranular precipitation does not form in sufficient amount in the fully austenitic weld metals to cause high-corrosion rates in the as-welded condition. In the presence of a small amount of ferrite, precipitation takes place both in the grain boundaries and around the relatively few ferrite patches (Fig. 5 (*b*)), and high-corrosion rates occur. When larger amounts of ferrite are present, intergranular precipitation is prevented by the preferential precipitation around the large number of scattered ferrite pools,[1, 7] and although attack is observed at these areas, there is little or no continuity to form a progressive path of attack and the rates are relatively low.

When these weld metals are subjected to a 1300° F. stress-relieving treatment, carbide and possibly sigma precipitation occur in all specimens. When these precipitates form in grain boundaries, continuous paths of attack are formed and the rates are very high. This effect may be seen in the specimens containing little or no ferrite. When sufficient ferrite is present, the precipitates show a preference for the scattered ferrite pools rather than for the grain boundaries, and though attacked by nitric acid there is no continuous path and the rates are low. At this heat treatment much of the ferrite has transformed to sigma, as shown by Fig. 6 (*a*) and confirmed by the change in magnetic rating shown in Table 6.

The stabilizing heat treatment at 1550° F. causes relatively high rates in the specimens containing little or no ferrite and excellent rates for the high-ferrite specimens. Referring again to Table 6 the magnetic rating indicates that most of the ferrite has transformed to sigma. This observation is confirmed by the photomicrograph shown in Fig. 6 (*b*). This result is not surprising in view of other investigations, both of welds[6] and of wrought steels,[8] that agglomerated sigma does not seem to be attacked in nitric acid.

In the annealed condition the rates are all satisfactory, which is to be expected. All precipitated carbides and sigma have either dissolved or become sufficiently agglomerated to have no effect on the corrosion rate. That ferrite is still present in the welds which originally deposited 8% ferrite is indicated by the relative magnetic rating in Table 6 and confirmed by metallographic observations (Fig. 6 (*c*)).

The annealed-plus-sensitized specimens all show ex-

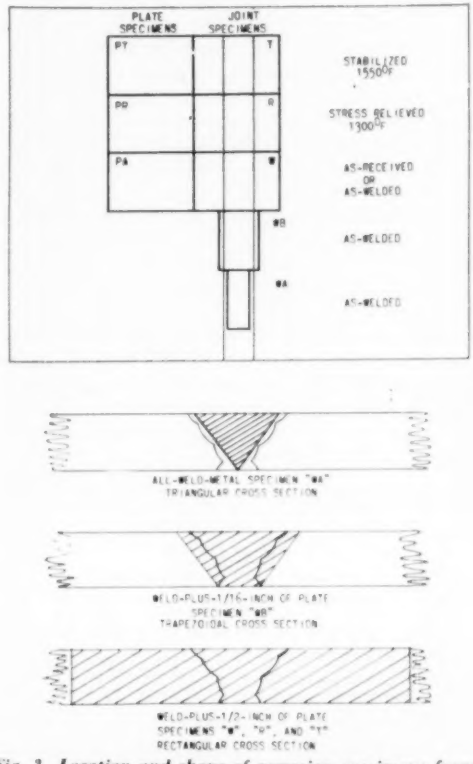


Fig. 3 Location and shape of corrosion specimens from welded joints

tremely high rates of attack, the greater the original ferrite content, the greater the attack. At first glance it is difficult to understand why the 1300° F. stress-relieving treatment should give so much lower rates in the highly ferritic weld metals than those which had an anneal prior to the 1200° F. sensitizing treatment. The explanation lies in the fact that the annealing treatment has greatly reduced the surface area of the ferrite pools,

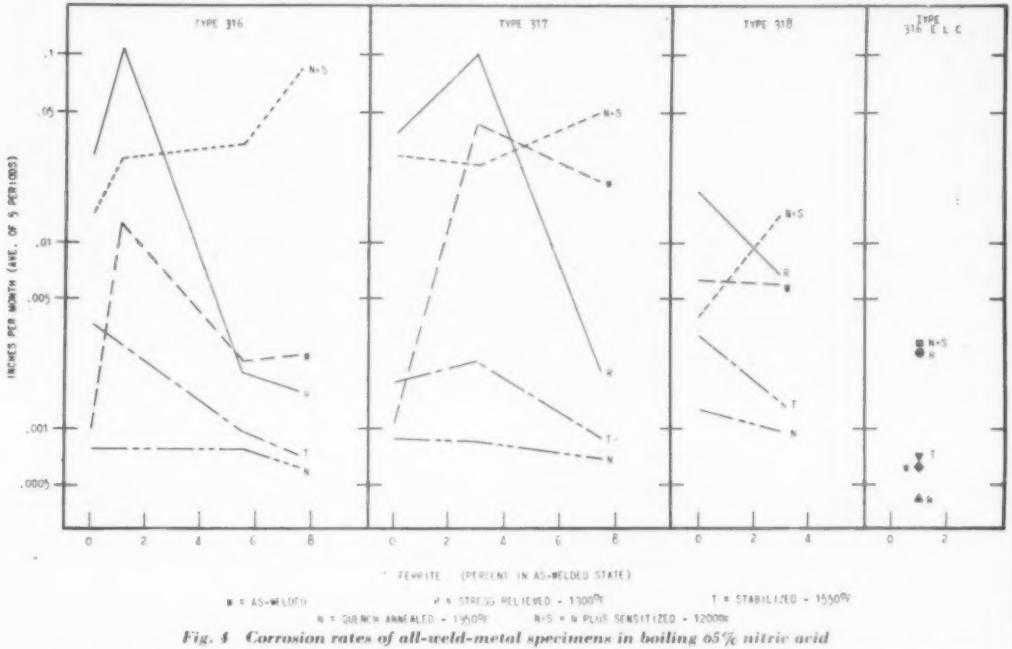
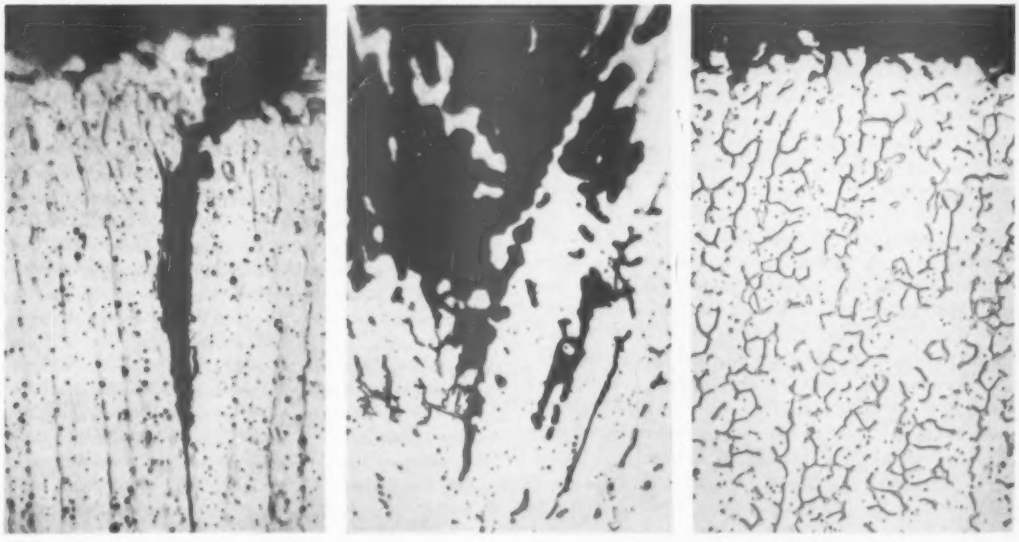


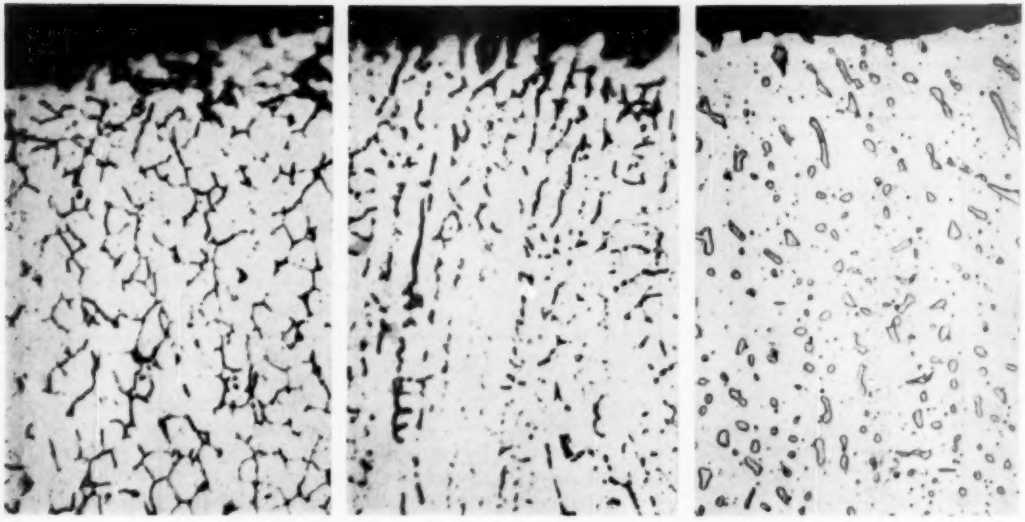
Fig. 4 Corrosion rates of all-weld-metal specimens in boiling 65% nitric acid



500 × (a) 500 × (b) 500 × (c)

Fig. 5 Type 316 weld-metal structures in the as-welded condition showing edge attacked by boiling 65% nitric acid

(a) Specimen 5170, fully austenitic structure, showing intergranular attack. (b) Specimen 5172 having 0–2% ferrite, showing both intergranular attack and attack at the ferrite patches. (c) Specimen 5173 having 6–9% ferrite, showing no intergranular attack and relatively little attack at the ferrite patches. Etchant: 10% oxalic acid, electrolytic



9 × (a) 300 × (b) 500 × (c)

Fig. 6 Type 316 weld metal originally containing 6–9% ferrite

(a) After a 1300° F. stress-relieving treatment, ferrite has largely transformed to sigma without agglomeration. (b) After 1550° F. stabilizing treatment, ferrite has almost completely transformed to sigma in a partially agglomerated form. (c) After a 1950° F. quench-anneal, some ferrite has gone into solution and the remainder has become agglomerated. Etchants: (a) and (b) 10% sodium cyanide electrolytic at 1 amp. per square inch for 30 sec., (c) 10% oxalic acid electrolytic

partly by solution but largely by the agglomeration of any remaining ferrite. As a result the subsequent sensitizing treatment permits most of the precipitation to occur at grain boundaries. It is believed that in the highest ferrite specimen the effective ferrite-austenite boundary area is reduced approximately to the level found in as-deposited 0–2% ferrite specimens, which explains the similarity in corrosion rate between specimens $5172R$ and $5173N + S$.

The tests in copper sulphate-sulphuric acid confirm some of the observations obtained from the nitric acid tests. On the basis of other published work[2–4,9] it is believed that the Aborn solution does not attack sigma and that evidence of intergranular attack is primarily attributable to carbide precipitation. In Table 5, therefore, it is not surprising to find that after the 1300° F. stress-relieving treatment intergranular attack occurs only in the specimens containing no ferrite, because the carbides precipitate at the ferrite patches if there are any present. For all the $N + S$ specimens, except the one containing the highest amount of ferrite, the annealing treatment dissolves any ferrite present in the as-welded condition (Table 6) and subsequent sensitization at 1200° F. causes intergranular attack to become evident in the Aborn test.

The bending of the Aborn test specimens gives support to the contention that fissures will be encountered in weld metals containing no ferrite, and those containing ferrite will become embrittled by the transformation of ferrite to sigma at 1300 and 1550° F. The embrittling effect is more pronounced as the ferrite content is increased.

Type 317 All-Weld-Metal Specimens

The similarity in the nitric acid corrosion rates for Types 316 and 317 in the various heat-treatment conditions is shown in Fig. 4. Only a few differences require comments, for it is believed that the corrosive mechanism in both cases is generally the same.

The highest ferrite Type 317 composition in the as-welded state fails to show the drop in corrosion rate exhibited by the Type 316 series. This specimen shows a very marked nonuniform attack as is seen in Fig. 7. After microscopic examination it was found that the areas which stand out in relief are areas containing visible sigma particles, presumably transformed from the ferrite by the heat of welding subsequent layers. The corroded areas show no evidence of sigma and the attack apparently follows the ferrite network. The most likely explanation for the striking difference in corrosion rate between these two areas is that where the time and temperature are sufficient to agglomerate the sigma (Fig. 7 (*b*)), little attack occurs, but where fine particles of sigma are believed to be present (although this cannot be observed) the corrosive attack is severe (Fig. 7 (*c*)). The Aborn test specimen treated similarly shows no evidence of intergranular corrosion and thus it is believed the attack by nitric acid is caused by a sigma precipitate.

Severe intergranular attack occurs in the stress-relieved and in the annealed-plus-sensitized fully austenitic specimens. Although the nitric acid rates are equally high for both conditions of heat treatment, the stress-relieved Aborn specimen failed in a brittle manner when bent only the slightest amount. With the

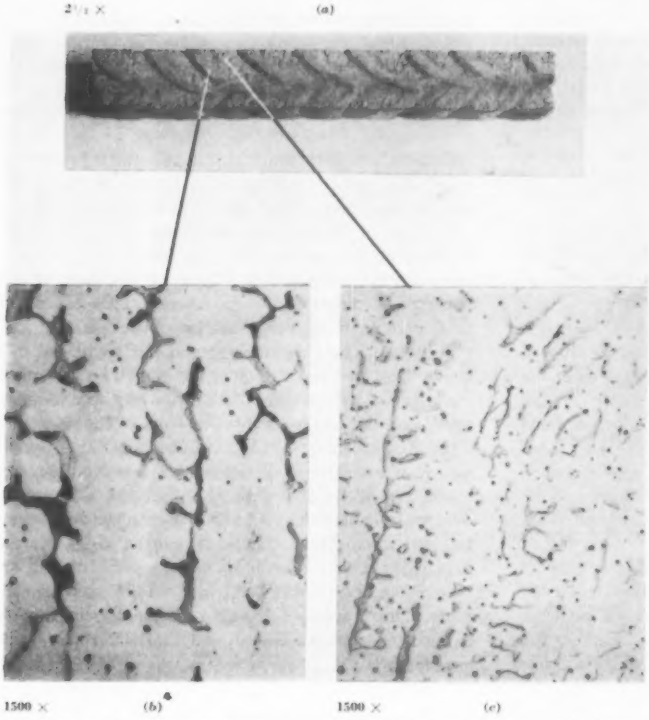


Fig. 7 Type 317 weld metal containing about 8% ferrite in the as-welded condition after 5 periods in boiling 65% nitric acid

(a) One edge of all-weld-metal corrosion specimen. (b) Microstructure of zone relatively resistant to nitric acid showing ferrite which has partially transformed to sigma. (c) Microstructure of zone deeply corroded by nitric acid showing ferrite in as-deposited condition. Etchant: (b) and (c) 10% oxalic acid, electrolytic. Reduced ½ in reproduction

exception of this specimen in which it is impossible to observe fissuring, fissures or hot tears are exhibited by all the fully austenitic bend specimens.

The loss in ductility resulting from any of the treatments involving temperatures from 1200 to 1550° F. is clearly demonstrated by the partially ferritic Aborn specimens. Since there is no evidence of intergranular attack, the embrittlement is apparently caused by the transformation of ferrite to sigma. Even the annealed specimen 5533*N*, shows a slight loss in ductility caused by a ferrite to sigma transformation (Fig. 8).

Type 318 All-Weld-Metal Specimens

The number of compositions which are available are too few to indicate any trend with respect to the original percentage of ferrite. Nevertheless, comparing the nitric acid rates for Types 316 and 318 as-welded specimens, the latter are slightly lower than the worst, but much higher than the best rates obtained on the Type 316 specimens. The addition of columbium has probably increased the tendency for fine particles of sigma to form even in the as-welded specimens. The stress-relieved and annealed-plus-sensitized corrosion rates reflect the stabilization of the carbon by columbium, resulting in somewhat lower rates than for the corresponding Type 316 specimens, but the results are far from acceptable on the basis of the usual standards. Again the presence of sigma probably explains the high-nitric rates on these otherwise stabilized grades, because, if intergranular carbides were present, the Aborn specimens would show evidence of intergranular attack. This is not the case. The stabilization heat treatment gives reasonably satisfactory nitric acid rates presumably because the sigma has become agglomerated, but in so doing the ductility is greatly reduced as shown by the bend angle and elongation of the Aborn specimens.

Type 316elc All-Weld-Metal Specimens

From only one composition of weld metal, the corrosion resistance of this relatively new composition is found to be very satisfactory. By lowering the carbon from 0.06% in Type 316 weld metals to 0.034, the average nitric acid corrosion rates are below 0.0008 ipm. for the as-welded, stabilized and annealed conditions. In the stress-relieved and in the annealed-plus-sensitized conditions, the high-corrosion rates are prob-

Fig. 8 Quench-annealed Type 317 weld metal originally containing 6–9% ferrite

Whereas the corresponding Type 316 weld metal in this condition shows no evidence of sigma, the ferrite-to-sigma transformation has taken place in the above Type 317 weld metal. Etchant: 10% sodium cyanide electrolytic at 1 amp. per square inch for 30 sec.

ably caused by finely precipitated sigma. No evidence of intergranular attack is observed in any of the Aborn specimens, and with the exce,tion of fissures, the bend ductility is good in all heat-treatment conditions. The lower bend angle and ductility of the annealed specimen are caused by a major fissure at the point of greatest deformation.

Plate and Butt Weld Specimens

When studying variations in weld metal composition it is generally preferable to use the type of all-weld-metal specimen described above, because the influence of the unaffected and the heat-affected areas of the plate does not confuse the data obtained. It has been common practice in accelerated corrosion testing of welds to employ joint specimens and to supplement the corrosion data with qualitative observations of the area of greatest attack. For this reason, it was decided to prepare butt welds using certain of the electrodes from each group in order that the nitric acid corrosion data could thus be correlated with data which may be obtained by other laboratories following this more common procedure.

The data shown in Table 6 are presented in graphic form in Fig. 9. The all-weld-metal corrosion rates from the pad specimens are plotted for comparison with the plate and joint data. These graphs reveal whether the plate corrodes more rapidly than the welds or vice versa. Generally, the average corrosion rate of the welded joint will be between the two unless the heat effect caused by welding produces an area of highly attacked plate metal adjacent to the weld. Only the Type 317 specimens show any attack in this heat-affected zone. Since the weld area represents approximately 25% of the total specimen surface in the joint specimen, the corrosion rate of the plate has a substantially greater effect on the average rate for the entire specimen than the corrosion rate of the weld metal.

In studying the relative attack on the various areas of the joint specimens, the influence of a high rate in one area upon the attack of a more resistant area is observed in many of the specimens. This is not surprising in view of the often cited caution that two specimens of varying rates should not be placed in a single flask for the nitric acid testing. The chromium ion resulting as a product of corrosion has been found to accelerate the corrosion rate.[10] Thus in the as-welded Type 316 specimens, the plate shows relatively little attack when unwelded, but shows relatively greater attack when welded with the fairly resistant fully austenitic electrode and still greater attack when welded with the electrode depositing 6–9% ferrite (Fig. 10). The reverse is found in most of the stress-relieved specimens where the high rate of attack on the plate metal appears to cause weld metal attack to an extent greater than that found in the all-weld-metal specimens.

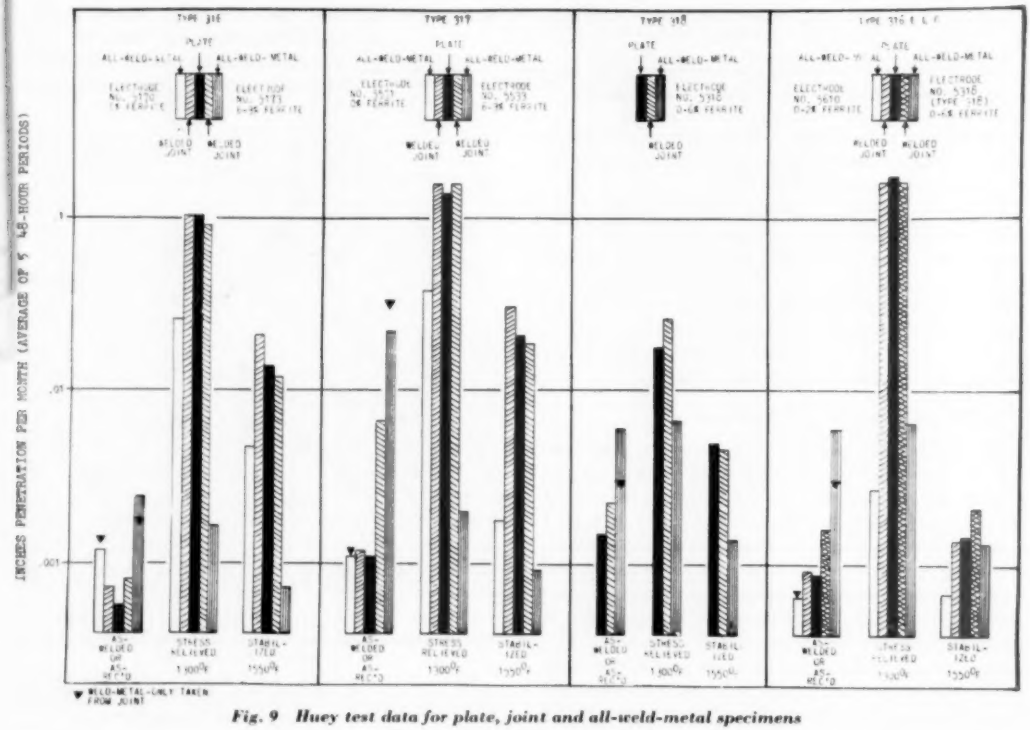
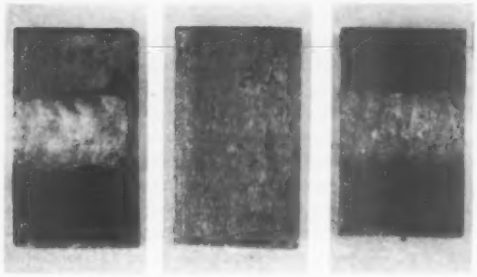


Fig. 9 Huey test data for plate, joint and all-weld-metal specimens



1× (a) (b) (c)

Fig. 10 Type 316 plate and butt welds in the as-welded condition

(a) Butt weld using fully austenitic weld metal. (b) plate only. (c) butt weld using 8% ferrite weld metal

In all four types of plate material, low-corrosion rates are observed in the as-received (mill annealed) condition, but under the two conditions of heat treatment employed, only the Type 316*elc* with a 1550° F. heat treatment would be considered acceptable. It is surprising that the 1300° F. treatment on this same plate gives the highest corrosion rate of any of the plates tested; this may well be caused by the intergranular precipitation of sigma which has been noted by other investigators. After 1300° F. the columbium-bearing Type 318 is the preferred alloy, though the rate is still far from acceptable. This same steel after stabilization at 1550° F. is improved, but not sufficiently to meet the usual acceptance standards.

Because the corrosion rates of the heat-treated plates are so high, the welded joint data for the same heat treatments have little significance, except that they serve to remove the fear that weld metals will be the primary source of corrosion failure. In the as-welded condition, the mill-annealed plate is invariably superior and therefore the as-welded weld metal data should be carefully studied. It is chiefly for this reason that it was considered desirable to obtain small triangular sections of the weld metal from the welded joints in order to compare these results with those obtained from the weld pads. The comparison is indicated on the bar graphs by the small triangles representing the rates from the welded joint. For convenience, the rates are tabulated below:

		All-Weld-Metal from	
No.	*Type*	*Weld pad*	*Welded joint*
5170	316	0.0012	0.0014
5173	316	0.0024	0.0016
5531	317	0.0011	0.0012
5533	317	0.0224	0.0334
5318	318	0.0060	0.0029
5610	316*elc*	0.0007	0.0007

As would be expected, the agreement is good when the rates are relatively low. The lack of agreement in 5173 is caused by the fact that the joint specimen shows scattered areas where the plate had not been completely removed. When the rates are high the weld metal usually shows nonuniform attack, as illustrated in Fig. 7, and therefore the relative proportion of exposed area which is readily attacked will govern the average rate measured.

The specimens containing approximately $^1/_{16}$ in. of plate on each side of the weld yield very little additional information. The specimen does offer the opportunity of exposing a greater proportion of the top and bottom weld metal surfaces with only a small amount of total plate area.

GENERAL DISCUSSION AND SUMMARY

In evaluating the net result of this investigation, three important factors must be kept in mind. First, in order to avoid any tendency for fissures or hot tears to form in the weld metal a small percentage of ferrite is very desirable. Second, unless the percentage of ferrite exceeds 4%, the nitric acid corrosion rates in the as-welded, stress-relieved or stabilized conditions may be high. Third, when substantial amounts of ferrite are present, its transformation to sigma causes a significant loss in ductility. From this, it would appear that the user who is attempting to specify the composition of the weld metal is facing a dilemma.

The best compromise between welds which tend to fissure and those which lose ductility is to retain present standards for weld metal compositions. To accept this solution means continuation of what laboratory technicians may consider to be excessive nitric acid corrosion rates, but until service experience shows that the present standards are unsuitable, it seems preferable to ignore the nitric acid data.

For Type 316 the occurrence of fissures may not be found to be a serious fault in fully austenitic compositions. By comparison with other commonly used austenitic weld metals the molybdenum-bearing alloys are generally less subject to hot-short cracking than balanced compositions of alloys containing no molybdenum. Should a particular service condition be found that clearly requires a weld metal free from ferrite, the problem of hot tears may not be serious unless the restraint is great. An excess of nickel beyond that needed to balance the structure, however, is believed to aggravate the condition and should be avoided.

The greater amount of molybdenum in the Type 317 weld metals will further tend to reduce hot shortness. The only fully austenitic composition studied contains a substantial excess of nickel. It is believed that fissures can be eliminated in a fully austenitic 317 weld metal, although it would be preferable to permit a small amount of ferrite if this condition is to be entirely avoided in highly restrained weldments.

The combination of molybdenum and columbium has always caused difficulty with hot tears and cracks, and the only solution appears to be an unbalanced structure. Should it be found that ferrite or sigma present in such unbalanced alloys is detrimental from

the corrosion standpoint, then a truly serious problem is encountered.

It is gratifying that the one composition of Type 316*elc* weld metal gives such a good account of itself both in corrosion resistance and in mechanical properties. Sufficient data are not available to establish composition limits for this latest addition to the list of welding electrodes and perhaps when they are available, it will be found that these excellent properties are not always produced. Comparing the weld metal data for Types 316*elc* and 318, it appears that the former can now be recommended for welding Type 316*elc* plate in preference to the latter.

It is well known that quench-annealed stainless alloys possess excellent corrosion resistance and ductility; weld metal is no exception unless fissures are present. Considerable confusion exists, however, among the various code-writing bodies regarding the optimum stress-relieving or stabilizing heat treatments to be used after welding. Loss in weld metal ductility occurs both at 1300 and 1550° F. if substantial ferrite is present, as this has been shown to transform to sigma. There is some indication that the ductility of these welds is less at 1550 than at 1300° F. In corrosion resistance all types of weld metal suffer at 1300° F. although at 1550° F. the resistance is apparently restored. While no data are available from this investigation, the apparent trend by industry to require higher stabilization temperatures, such as 1625° or even 1700° F. would be expected to give better ductility and better corrosion resistance. On the other hand, the use of 1300° F. for stress relieving would seem to be unsuitable for corrosion service.

An attempt has been made to explain the mechanism of the corrosive attack partly on the basis of the observed microstructure of the specimens and partly on the explanations offered in the many excellent papers recently presented. Briefly the theory postulates the coexistence of a finely precipitated sigma phase and carbides. If these precipitates are in grain boundaries or around connected ferrite patches, a continuous path is offered for the progression of the corrosive attack. If, on the other hand, these precipitates occur primarily around the discontinuous ferrite patches, the corrosive attack is much less rapid. The stabilizing heat treatment of 1550° F. is believed to agglomerate the fine precipitate and render it harmless. The metallographic evidence is convincing that sigma particles resulting from the transformation of ferrite are relatively unattacked by nitric acid.

The 500-hr. tests in copper sulphate-sulphuric acid seem to reveal only intergranular carbide precipitation and not the postulated sigma precipitation. Thus, the columbium stabilized specimens and the extra-low carbon specimens show no evidence of intergranular attack by this test.

The data were collected primarily on specimens prepared from weld pads, but several of the electrode compositions were used to prepare butt-welded specimens. From these welds it is found that small triangular specimens of weld metal give nitric acid corrosion rates quite comparable to those obtained from the weld pads. The average rates measured on the joint specimens are influenced considerably by the resistance of the plate material.

The evaluation of the suitability of a material for corrosive service cannot now be satisfactorily accomplished by accelerated laboratory corrosion tests. Such tests, however, may become a very valuable tool in the hands of technicians who are properly schooled by service experience in the application of such tests. Actual records of critical service experience for comparison with laboratory tests are not available at present. It is hoped that the program of field corrosion testing now being set up by the High-Alloys Committee of the Welding Research Council will provide the background needed to permit evaluation of corrosion resistance by accelerated laboratory tests.

ACKNOWLEDGMENT

The authors gratefully acknowledge the cooperation of Dr. M. H. Brown and W. B. DeLong of E. I. duPont de Nemours and Co., Engineering Research Laboratory, during the course of this investigation.

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Discussion by V. N. Krivobok

This, the latest paper by Messrs. Schaeffler and Thomas, whose names have now become synonymous with thoughtful research on the metallurgy and welding of stainless steels and on welding electrodes in general, is another valuable addition to our library on the above subject. The paper inspires careful study. Having done so, I would like to put down those comments or questions which I believe to be pertinent.

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My first comment is definitely in the nature of a question. While describing the procedure by which eleven variable compositions of electrodes were prepared, it is stated that the same heat of core wire was used, but that the weld-metal composition was adjusted by additions of ferro alloys to the coatings. In other words, to bring either chromium, nickel, molybdenum or columbium to the desired level, additions of these elements were made through coating. Is it not proper to suspect that introducing these elements in this manner is not the same, metallurgically speaking, as if the desired composition of the weld metal was achieved by having core wire of the proper analysis? To illustrate the point, let us consult Table 1. This table tells us that the chromium composition of the electrode wire was 18.73%. Weld 5170 shows a chromium content of 17.78%, that is, almost 1.0% of chromium was lost. In weld 5319 the chromium content is 18.89%, and no loss of chromium has been experienced (the very little gain is probably an experimental error in analysis). What happened to the 1% chromium in weld 5170? Some of it, quite possibly, will be found in the weld in the form of oxides. What effect would the presence of such and other oxides have on corrosion rates?

I regret that I do not quite follow the discussion of the effect of ferrite pools on the rate of attack. It is stated in the paper that "apparently intergranular precipitation does not form in sufficient amount in the fully austenitic weld metals to cause high corrosion rates in the as-welded condition." In the presence of a small amount of ferrite, it is stated, precipitation takes place at the grain boundaries and around "the relatively few ferrite patches," and high corrosion rates occur. In the sentence quoted above the word "apparently" is of considerable importance. One is naturally curious to know why intergranular precipitation does not take place in the fully austenitic weld metals.

An interesting suggestion follows, namely, we are told that when *larger* amounts of ferrite are present, intergranular precipitation (in austenite, VNK) is prevented by preferential precipitation around the large number of scattered ferrite pools. It is not readily understandable how carbide precipitation in austenite, a matter of solid solubility at any given temperature, can be prevented by preferential precipitation around numerically fewer grains of ferrite. I cannot agree with this statement, unless I misunderstand its meaning. Is it proposed for us to believe that if the structure contains both ferrite and austenite, the only carbides that would be precipitated at 1300° F. will be precipitated in the ferrite patches? Even though ferrite grains are present, some carbides are dissolved in austenite and under certain conditions these carbides will precipitate out. The only condition under which no precipitation of carbides is to be expected at the grain boundaries or within the grains *of austenite* would be if all the carbides diffused into the patches of ferrite. This cannot happen on logical grounds. My experience in these matters has been just the opposite. Disintegration, due to carbides out of solution, will be observed even in the presence of considerable amounts of ferrite.

Further discussion of the effect of the 1300° F. stress-relieving treatment (which, we agree with the authors, results in carbide and possibly sigma precipitation and would be expected to occur in all steels under test) will be most welcome. The explanation is repeated that when sufficient ferrite is originally present in the weld, the precipitates show a preference for the scattered ferrite pools rather than for the grain boundaries. For this reason, even though the ferrite pools are attacked by nitric acid, there is no continuous path and the corrosion rates are lowered. The authors suggest that with this treatment, namely, 1300° F., much of the ferrite has transformed to sigma, submitting their Fig. 6 (*a*) and also magnetic readings in support of their belief. Assuming that ferrite *has changed* to sigma, it is difficult to accept the explanation for the lower rates of attack. Most of us believe sigma phase to be, and the authors themselves have it so described less corrosion-resistant than other constituents. Should we not, therefore, expect relatively high rates in the presence of sigma phase?

One observation which is quite interesting is that 2 hr. at 1550° F. is enough to agglomerate sigma phase. Frankly, this is rather surprising and I think that the authors themselves believe that under the described conditions of heat treatment, one might expect only *partially* agglomerated sigma.

It is most reassuring that this good technical paper treats the various aspects of the subject in an impartial manner. For example, it is suggested in this paper that the presence of ferrite in the welding bead may lead to embrittlement because ferrite under certain conditions of heat treatment will be transformed to sigma phase. This is a distinct possibility and some of the work which it was my pleasure to carry out in cooperation with Mr. Thomas justifies this belief:

To continue our discussion, a suggestion which is not easily explained is presented by annealed specimen 5533N which is described as having suffered a slight loss of ductility caused by a ferrite to sigma transformation. Since annealing of the sample was done at 1950° F. is it not for the first time that we find sigma formation at this temperature?

I believe a comment is warranted regarding Fig. 9. The authors arrive at an important observation for type 316 stainless. This observation is that in the as-welded condition—be it all weld-metal, weld joint or plate—the rates are much lower than in the stress-relieved or stabilized condition. If it is true it is indeed significant: The stabilizing treatment has been suggested, at least in other alloys, to minimize corrosion by affecting agglomeration of precipitated carbides.

I would like to suggest that while the explanation of various observed differences in the rate of corrosion

Weld Impact Results—Charpy Keyhole Notch

Weld type	*Test temp., ° F.*	*As-welded, ft.-lb.*	*Annealed, ft.-lb.*	*Stress relieved— 1200° F., ft.-lb.*	*Stabilized— 1500° F., ft.-lb.*
316	Room	27, 5, 34, 5, 27, 30, 5 (*30*)*	31, 5, 36 (*33, 5*)	34, 30, 31, 5 (*32*)	26, 30, 29 (*28*)
	−320	19, 14, 21 (*18*)	22, 22 (*22*)	14, 13 (*13, 5*)	14, 5, 11 (*12, 5*)
316F	Room	32, 31, 5 (*31, 5*)	31, 5, 36, 5, 40, 5, 40 (*37*)	27, 25 (*26*)	11, 5, 10, 5 (*11*)
	−320	17, 5, 19, 5 (*18, 5*)	23, 5, 27, 5 (*25, 5*)	7, 7, 5 (*7*)	3, 2, 5 (*2, 5*)
318	Room	27, 5, 27, 5 (*27, 5*)	33, 29, 5, 30 (*31*)	30, 32, 5 (*31*)	22, 21 (*21, 5*)
	−320	9, 17, 5, 17 (*14, 5*)	21, 5, 19 (*20*)	17, 5, 8, 5, 18 (*14, 5*)	13, 12, 5 (*12, 5*)
318F	Room	20, 5, 23, 15, 22, 20 (*20*)	26, 25 (*25, 5*)	21, 5, 17, 19 (*19*)	9, 5, 8 (*8, 5*)
	−320	11, 5, 10, 5 (*11*)	16, 18, 10 (*14, 5*)	7, 10, 9 (*8, 5*)	5, 5, 5 (*5*)

* Figures in italic in parentheses indicate averages.

attack is most stimulating and most conducive to careful appreciation of the role played by carbides, sigma and ferrite, one possibility was not considered. The weld bead is a cast alloy. A cast alloy is a segregated metal. Segregation means different rates of corrosion on a minute scale. It may even mean *accelerated* corrosion due to the adjacent areas of different compositions and, hence, of different levels of resistance to attack. Thus, is it not possible that much of the difference in corrosion rates may be attributed to the segregation which is impossible to avoid and to evaluate in the case of cast alloys? The microphotographs which are submitted with this interesting paper definitely show the presence of segregation in the form of dendritic patterns.

It is a distinct pleasure for me to submit to all those who are interested in the welding of stainless steels the above suggestions which, while expressing my thoughts, are designed to suggest attentive study of a valuable paper and the concepts which this paper postulates.

Discussion by W. O. Binder

Messrs. Schaeffler and Thomas have presented some very interesting and valuable data on molybdenum-bearing 18–8 steel welds, and they are to be commended in their efforts to reveal the influence of weld-metal composition on corrosion resistance, ductility and hot-tearing. The tendency for certain of these steels to exhibit high corrosion rates in nitric acid after welding, with no signs of excessive corrosion in other testing media, has been extremely confusing from the standpoint of specifying the composition of the weld metal for service. Their observations that the nitric acid loss is associated with the formation of sigma are in general agreement with our own experience and with those of others reported during the recent A.S.T.M. symposium on Evaluation Tests for Stainless Steels.

The authors have indicated a peak in the nitric acid corrosion rate curve vs. ferrite content occurring at about 2% ferrite content in the weld. They indicated that this peak would have been considered a "freak" had it not occurred in both types 316 and 317 steel welds at about the same ferrite content. It has been our experience that sand castings of types 316 and 317 steel in the as-cast condition do not show such a peak in nitric acid corrosion rate as the ferrite content of the casting increases. For example, we have observed that the corrosion rate of sand-cast Type 316 steel containing 2.35% molybdenum and 0.06% carbon decreased gradually from 0.09-in. penetration per month to 0.0008-in. penetration per month as the nickel content was increased from 9 to 14% in increments of 1 to 2%. A similar trend was noted in the Type 317 steel castings containing 0.06% carbon and 3.5% molybdenum. The latter decreased from 0.01- to 0.001-in. penetration per month as the nickel content increased from 10 to 16%. The lower rate of the latter steels in nitric acid is due to the almost complete transformation of ferrite to sigma during cooling in the sand molds. The lack of correlation in behavior between sand castings and weld metal may be due to differences in cooling rates.

It will be noted in Table 1 of this investigation that in some cases the ferrite content of the weld has been increased by changing both the nickel and chromium content of the weld. It appears to the writer that the corrosion rate trends, shown in Fig. 4, are not altogether a function of the amount of ferrite present in the weld but may be due to changes in the composition of the sigma phase and ferrite resulting from increasing the chromium content. Perhaps the authors may have some comments to make on this point.

As the authors have pointed out, three important factors must be kept in mind when evaluating the results of the investigation. First, a small percentage of ferrite is desirable to avoid fissures or hot-tears in the weld metal. Second, the nitric acid corrosion rate is high unless the percentage of ferrite exceeds 4%. Third, when substantial amounts of ferrite are present, there is a loss of ductility after stress-relieving due to the transformation of the ferrite to sigma phase.

To balance these divergent factors, it is obvious that some compromise is required. Because the need for crack-free welds is so important, it appears unwise to make any sacrifices in that direction unless the conditions of restraint are exceedingly mild. The compromises, therefore, must be made with respect to ductility or corrosion resistance.

The authors suggest that we should retain present standards for weld metal and disregard the lack of

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corrosion resistance in nitric acid until service experience shows that the present standards are unsuited. While this represents a reasonable attitude on the matter of corrosion resistance, I am unable to determine from the text whether the authors have reached a conclusion regarding the importance of cold ductility. It is believed that one of the important problems in connection with the wider usage of these steels is the cost of fabrication and that in order to simplify the fabrication problem, the composition of the weld should embody as much ductility as possible, consistent with adequate corrosion resistance. In Table 5, the authors have shown that unless the molybdenum content of the weld is limited to about 2%, it is impossible to meet the bend-test requirement of 20% after stress-relieving at 1300 to 1550° F. It would be of interest to know whether the authors think it advisable to eliminate the Type 317 electrodes, except for special application wherein the higher molybdenum content is needed for corrosion resistance, because of its poor ductility.

I am in agreement with the authors' comments concerning the confusion which exists regarding the optimum stress-relieving heat treatment to be used after welding. Loss in weld-metal ductility occurs both at 1300 and 1550° F. if substantial ferrite and more than about 2% molybdenum are present in the steel. Higher stress-relieving temperatures than 1600° F. would be expected to give better ductility and corrosion resistance; on the other hand, such treatments produce greater distortion troubles. The use of 1300° F., while it is less harmful to ductility, decreases corrosion resistance and is only suitable if the carbon content of the weld is very low or a stabilizing element is present. The problem is such a dilemma to the user of these steels that the need for further work to produce stress-relieving heat treatments which will provide satisfactory relief of stress without marked loss of corrosion resistance cannot be stressed too highly. It is believed that more study of the reduction of stress by the use of temperatures in the range of 800 to 1000° F. should be conducted as a means of avoiding the present difficulties.

Discussion by R. H. Aborn

The paper by Messrs. Schaeffler and Thomas on "Corrosion Resistance of Mo-Bearing Stainless Steel Weld Metals" is a significant contribution, for, so far as I am aware, it provides the first systematic study of the effects of heat treatment on the Mo-bearing austenitic grades of stainless steel weld metal.

The stand they have taken regarding the retention of present standards for weld-metal compositions, notwithstanding the high nitric acid corrosion rates which may be associated with some compositions, is highly commendable.

My first inquiry concerns the reproducibility of their observations on nitric acid corrosion rates. So far as I have been able to ascertain from reading the manuscript, the authors have conducted no duplicate tests and I have in mind the paper by Meunier and Schnadt in *Arcos*, **16**, (94), 2161–2174 (Sept. 1939), in which they demonstrate the poor reproducibility of the nitric acid test results on 18–8 weld metal.

I hope that the magnetic readings will be checked by microscopic examination, at least in the 1950° F. quench series in which the authors found indication of an amazing drop in ferrite content under conditions in which one would not expect the formation of sigma. Our experience with 18–8 ingots is that the proportion of delta ferrite does not change significantly by any treatment other than hot working. The magnetic test will presumably include any cold work ferrite resulting from specimen preparation. This effect, however, is possibly small owing to the relatively high nickel content.

I infer that the statements that sigma formed from ferrite at 1550° F. is relatively unattacked by nitric acid and would be interested to know whether the authors have any information leading them to believe that sigma, formed at a similar temperature from austenite only, shows a similar high resistance to nitric acid.

I believe all test names should be objective, with the aim of indicating so far as possible, the type and nature of the test. We merely adapted the $CuSO_4$–H_2SO_4 test to our needs. As the concentrations of $CuSO_4$–H_2SO_4 are close to 1% and 8% respectively, I suggest this modification be called the 1–8 $CuSO_4$–H_2SO_4 test, and it might be further abbreviated to copper sulfuric test.

Discussion by P. Payson and L. C. Chang

The data presented by the authors undoubtedly will be of considerable interest and value to industry. There is some question, however, about the dependability of the explanation offered by the authors to account for the poor corrosion resistance of some of the as-welded and stress-relieved samples. Thinking it would be wholesome to have some substantiating evidence on the constituents in these samples, we asked the authors to let us run X-ray diffraction patterns on electrolytic extractions of test pieces used in the authors' corrosion tests. The authors graciously agreed to this and sent us several of the samples which had been used for the acid copper sulphate tests, namely, the as-welded (W) and stress relieved (R) samples of 5532 (Type 317), 5317 (Type 318) and 5610 (Type 316*elc*).

The extraction procedure used has been mentioned previously.[1] To make certain that very fine precipi-

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[1] Discussion of "Influence of Carbon and Molybdenum on the Intergranular Corrosion Resistance of Austenitic Chromium Nickel Steels with and Without Columbium," by W. O. Binder and C. M. Brown, *A.S.T.M. Bull.* (June 1949).

tates are not overlooked in the X-ray diffraction analysis, the main residue obtained in the electrolytic extraction is stirred up in a 50% ethyl alcohol–50% water solution and the fine particles which float on the surface of this solution are collected, washed and dried, and mounted in a 10-cm. Debye-Scherrer camera. The X-ray pattern is made with Cr K radiation.

Since the samples which had been used in the acid copper sulphate test were quite small, we were not altogether satisfied that the results we obtained from these pieces were absolutely dependable. We therefore asked the authors to send us additional weld pads of the same materials in both the as-welded and stress-relieved conditions. The new samples we received were large enough so that we felt sure we obtained dependable results. In the main the analyses of the extractions from the second set of samples agreed with those of the first. The data obtained are tabulated below:

Sample	Nitric acid rate, in./mo., Table 3 of paper	Bend angle acid copper sulphate test, Table 5 of paper	X-ray analysis of electrolytic extraction* — First sample		Second sample	
5532W (317)	0.0442	170	Sigma	(2)	Sigma	(2)
			$M_{23}C_6$	(1)	$M_{23}C_6$	(2)
5532R (317)	0.103	140	Sigma	(2)	Sigma	(2)
			$M_{23}C_6$	(2)	$M_{23}C_6$	(2)
5610W (316*elc*)	0.0007	180	Sigma	(1)	Sigma	(2)
5610R (316*elc*)	0.0027	180	Sigma	(1)	Sigma	(2)
			$M_{23}C_6$	(1)	$M_{23}C_6$	(1)
5317W (318)	0.0064	130	CbC	(2)	Sigma	(Trace)
					$M_{23}C_6$	(Trace)
					CbC	(2)
5317R (318)	0.0186	105	CbC	(2)	Sigma	(Trace)
					$M_{23}C_6$	(Trace)
					CbC	(2)

* (1) designates faint line; (2) more intense line.

Thus, it appears from these results that although sigma was present in all samples, carbide was present also in all samples showing high rates of corrosion. Since sigma was found without carbide in the 316*elc* material which had a very low rate of corrosion in the as-welded condition, and sigma was found with carbide in the 316*elc* material which had a higher rate of corrosion in the stress-relieved condition, it follows that the higher rate of corrosion in the stress-relieved steel was attributable to the presence of precipitated carbides rather than sigma, in spite of the fact that this steel contained only 0.034% carbon. This finding contradicts the authors' explanation for the cause of the higher corrosion rates in this steel in the stress-relieved and in the annealed-plus-sensitized conditions. The fact that the acid copper sulphate solution did not attack the samples in which $M_{23}C_6$ was found merely indicates that the acid copper sulphate test used was much less sensitive than the nitric acid test in showing the presence of precipitated carbides.

It is of considerable interest to note that the columbium carbide was the dominant constituent in the extraction product from the Type 318 samples. Although a trace of the $M_{23}C_6$ (chromium) carbide was also found in these samples it seems reasonable to conclude that the cause of the high corrosion rates in these samples was the presence of fine columbium carbides rather than chromium carbides.

Authors' Reply

The authors are grateful to Messrs. Krivobok, Binder, Aborn and Payson who have taken the time to review our work and who have brought out significant points for critical study.

Dr. Krivobok has correctly pointed out the deviation in chromium content from the 18.0% desired in the specimens 5170, 5171, 5172 and 5319. Although these were all prepared from a single heat of core wire, the desired variation in composition has been achieved by introducing metal powders into the coatings. The normal oxidation loss of chromium in arc welding is shown by specimen 5172, which has no metal powders excepting the usual deoxidizers, and results in a loss of 0.51% Cr (18.73 in the core wire to 18.22 in the weld deposit). It is relatively simple to increase the nickel to 13 and 14% in specimens 5171 and 5170, but in so doing the chromium content decreases, not by any differences in oxidation as Dr. Krivobok implies, but by dilution from the added nickel powder. In order to decrease the nickel to 11% for Specimen 5319 it was necessary to dilute the filler metal by additions of powdered iron. The iron would also cause an excessive dilution of chromium and therefore ferro-chromium was also added. Actually the resulting chromium in this specimen was a little greater than desired, but since it gave a ferrite content almost exactly between that of specimens 5172 and 5173, it did not seem necessary to make another attempt to adjust the chromium content.

Dr. Krivobok's queries as to the formation of precipitates and their effects on nitric acid corrosion resistance indicate some misunderstanding of our explanations. Intergranular precipitation *does* occur in fully austenitic weld metals, but not in sufficient amount to cause high corrosion rates in the as-welded state. After a 1300° F. stress relief, additional precipitation occurs at the grain boundaries, and the corrosion rates are much higher. When about 4% or more ferrite is present, all precipitation occurs around the ferrite patches (actually it is impossible to determine microscopically after applying the usual etching techniques where the grain boundaries are!). In the absence of intergranular precipitates in either the as-welded or the 1300° F. stress-relieved conditions, the attack by nitric acid is limited to the ferrite boundaries which do not present a continuous path for progressive attack. In weld compositions containing small percentages of ferrite, intergranular precipitation occurs in both the as-welded and stress-relieved conditions, and the corrosive attack is greater in these specimens because we have not only

the intergranular attack which gives a continuous path for corrosion, but the attack around the ferrite patches which helps to widen the approach to the grain boundary as shown in Fig. 5 (*b*).

It is not surprising that questions should arise regarding the apparently anomalous behavior of sigma in resisting nitric acid corrosion. Throughout this work we have found evidence of the transformation of the ferrite to sigma, i.e., loss in ductility, change in magnetic rating and microscopic examination. The nitric acid corrosion rates, however, do not show any unusual attack on the sigma constituent when present in discontinuous massive particles resulting from the ferrite transformation. The presence of a fine sigma precipitate which *cannot* be observed microscopically is postulated to explain high corrosion rates which cannot be accounted for by the presence of carbide precipitation alone. For example, why should the corrosion rates of the Type 317 alloys having the same carbon content be so much higher than Type 316 alloys unless a large amount of such a sigma precipitate were present; or why should all the partially ferritic specimens in the as-welded condition give so much higher rates than is normally found in non-molybdenum stainless weld metals of the same microstructure. Other investigations recently reported contribute evidence in support of the concept that a fine precipitate of sigma causes high nitric acid rates; when present in an agglomerated form, such as results from a transformation from the ferrite patches, the attack is relatively slight. We agree with Dr. Krivobok that the agglomeration of sigma at 1550° F. for 2 hr. may be only partial, but apparently it is sufficient to reduce greatly the nitric acid corrosion rates.

The presence of sigma and the loss of magnetism in annealed specimens has been questioned both by Dr. Krivobok and by Dr. Aborn. Figure 8, showing sigma in the annealed Type 317 specimen, was included because it was surprising to us to find practically all of the secondary phase in the form of sigma. Furthermore, this observation explained the change in magnetic rating from 12+ in the as-welded condition to 2 in the annealed condition. As a result of these questions, we decided to anneal the as-welded Type 317 corrosion specimen (5533W). Unfortunately, we were unable to reproduce either the low magnetic rating or the large percentage of sigma. The same specimen was again heated to 1950° F., this time slowly at a rate shown in Fig. 1, and while the magnetism was still further reduced to a value of 9, this was disturbingly far from the value of 2 found originally. Since no more weld metal of this composition was available for further tests, we turned to specimen 5532W which was cut in two equal parts, both of which were then annealed at 1950° F., one by rapidly heating in a furnace previously set at the desired temperature and the other by slow heating as above. A more sensitive method of magnetic rating was employed, involving the suspension of the same type of magnet from a triple-beam balance and determining the weight required to separate the magnet from the specimen. In the as-welded condition the rating by this method showed about 14 gm., whereas after the anneal the rating was 2 gm. on both the rapidly heated and slowly heated specimens. These magnetic ratings agree substantially with the values reported for this weld metal in Table 6.

The four photomicrographs in Fig. A were taken of representive areas in this specimen. The upper two photomicrographs with the sodium cyanide etch alone outline the sigma particles only and show substantial amounts in the right-hand photo, similar to Fig. 8. Ferrite patches in the identical areas are identified in the lower photographs only after subjecting the specimen to an additional etch with oxalic acid. These observations do not answer the question as to whether or not the sigma formed at the annealing temperature, because it is conceivable that the sigma was present in certain areas in the as-welded condition. If so, the loss in magnetism must be attributed to the solution of ferrite, an explanation which apparently does not agree with Dr. Aborn's experience, but is confirmed by the observation of magnetic ratings of the other specimens. On the other hand, very few of the other specimens show such a great loss in magnetic rating, suggesting that the solution of ferrite is only partly responsible for the loss in magnetism and the formation of sigma accounts for the remaining observed difference. The inability to obtain reproducible results after a 1950° F. anneal indicates the need for more investigation of other weld-metal specimens before definite conclusions can be drawn.

The authors are grateful to Dr. Krivobok for raising the significant point on the role of segregation in the corrosion resistance of weld metals. No mention was made of this point only because it was felt to have a minor influence, if any. In certain studies of stainless welds microscopic segregation of the austenite phase is believed to play an important role, but in this case, there seemed to be no observed result which was not adequately explained by the presence of ferrite, sigma or carbides.

Mr. Binder's experience with cast alloys is extremely valuable, particularly since weld metal and castings are frequently thought to be similar. The fact that the two forms of metal perform quite differently in the nitric acid test suggests that considerable caution should be exercised in carrying the analogy of the two processes too far. As he suggests, the lack of correlation is probably due to the difference in cooling rates.

It is interesting to speculate on the results which would have been obtained if it had been possible to hold the chromium content more constant in the Type 316 series as Mr. Binder suggests. The relatively small difference in chromium content between 5172 and 5319 (18.22 and 18.89%, respectively) has produced enormous differences in corrosion rates, while the large difference in chromium content between 5319 and 5173 (20.55%) has resulted in relatively small differences in corrosion rates. These observations lead us to the conclusion that the chromium level in Type 316 had

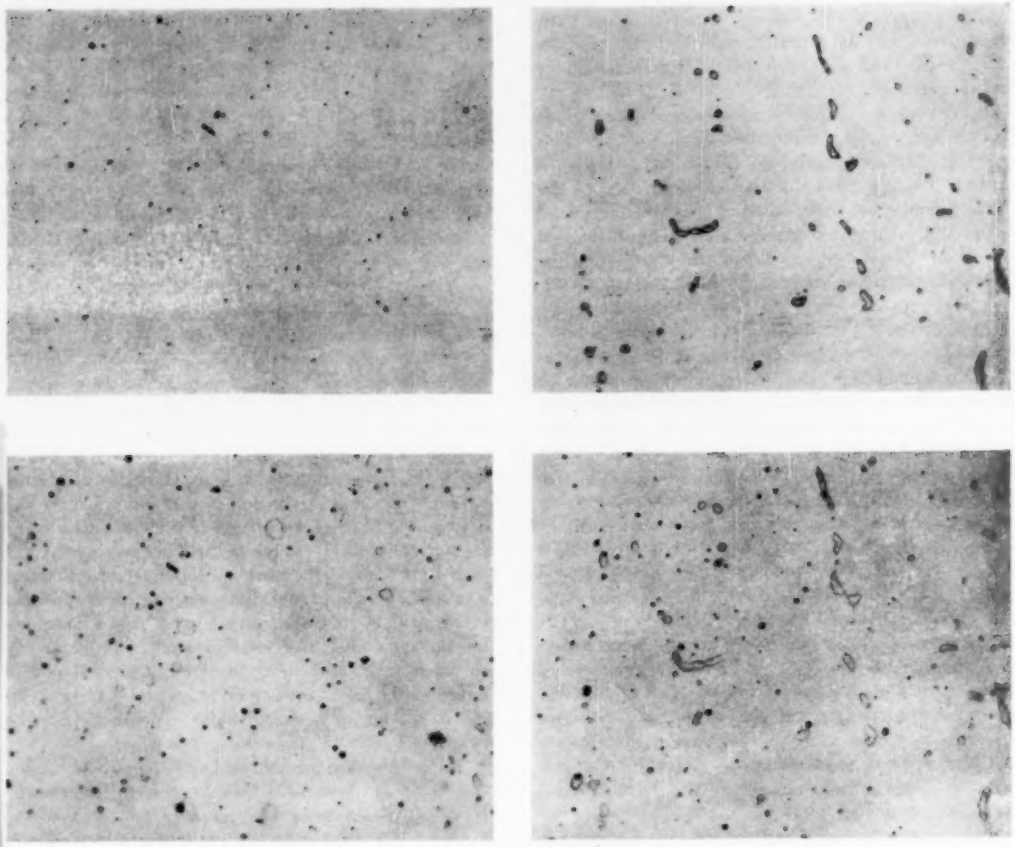

Fig. A. Specimen 5532. Quench-annealed, Type 317 weld metal originally estimated to contain 4–7% ferrite. Upper photomicrographs show structure after an etch with 10% sodium cyanide electrolytically at 1 amp. per square inch for 30 sec. to reveal sigma only. Lower photomicrographs show identical areas after an additional electrolytic etch with 10% oxalic acid to reveal ferrite. Area in the left-hand photos shows ferrite with almost no sigma; area at right shows sigma with almost no ferrite. × 1000

little effect on the corrosion resistance excepting as it influenced the amount of as-welded ferrite. Nevertheless, we agree that the chromium level should not be overlooked in analyzing corrosion data because in non-molybdenum weld metals it is found to have a profound effect.

Mr. Binder's inquiry as to our recommendation on the application of standard compositions of Type 317 electrodes may be answered by pointing out that satisfactory ductility can be obtained in the as-welded and annealed conditions. Since most of the applications of Type 317 electrodes are not heat-treated after welding, and since the 3% molybdenum imparts greater corrosion resistance to certain media, there would appear no good reason for discouraging its use in the as-welded condition even though the nitric acid test does not show adequate corrosion resistance. In the annealed condition, of course, Type 317 welds show good corrosion resistance and good ductility.

Dr. Aborn raises an important point on the reproducibility of nitric acid corrosion data on weld metal. As he has surmised the values reported represented tests on single specimens in each condition. Previous investigations have convinced us that the reproducibility of duplicate specimens was of the order of 10% which was adequate for the purposes of this investigation. Though not reported in this paper, certain specimens were first tested in our laboratory, then reground and retested by another laboratory with the following results (reported to the fifth decimal point):

No.	*Areas lab.*	*Outside lab.*	*Av.*	*Deviation, %*
5170W	0.00146	0.00120	0.00133	10
5170N	0.00087	0.00074	0.00080	9
5171W	0.00088	0.00123	0.00105	16
5171N	0.00069	0.00075	0.00072	4
5171T	0.00201	0.00213	0.00207	3

The 16% deviation in Specimen 5171W is believed to be unusual because of failure to remove all of the attack occurring in the first corrosion test. In one case a new

specimen was prepared from the same electrode with the following results:

No.	*Pad 1*	*Pad 2*	*Av.*	*Deviation, %*
5531W	0.00106	0.00128	0.00117	9

Greater deviations occur in some cases when the weld specimens are obtained from different types of weldments as is seen in Fig. 9 and in the text under discussion of the all-weld-metal values from pad welds and from welded joints. In specimen 5318W (Type 318) the pad weld gave twice the corrosion rates of the two triangular specimens machined from joints in Type 318 or in Type 316*cle* plate. Possibly duplicate pad specimens in this condition would have been desirable in view of the consistent values obtained from the two triangular specimens. Finally, a comparison of the rates obtained on all specimens of the 5170 and 5171 series, which are fully austenitic Type 316 analyses but differ by 1% in nickel, shows remarkably good correlation excepting in the stabilized condition; in our opinion this uniformity justified plotting the average results from these two compositions as representative of fully austenitic weld metals in Fig. 4. While we agree with Dr. Aborn that the accuracy would have been improved by testing duplicate specimens, we do not believe that the trends observed would have been materially changed.

We have no information which would answer Dr. Aborn's question regarding the influence of sigma which has transformed from austenite at 1550° F. On the basis of published work, however, we question the inference that sigma does form from austenite, but rather prefer to believe that it forms from minute crystals of ferrite which may occur at grain boundaries or other discontinuities of the lattice structure and which then grow to a size which can be detected.

The data contributed by Mr. Payson are greatly appreciated. The presence of sigma in all specimens which were tested is gratifying confirmation of our suspicions. In the Type 317 specimens, sigma is clearly found by microscopic examination in large particles associated with the ferrite patches. But in types 318 and 316*cle* no sigma could be detected. Although Mr. Payson's evidence in the case of the 316*cle* would seem to indicate little influence of the finely precipitated sigma particles on the nitric acid corrosion rates, we believe that the story is still incomplete because we have not yet determined the form, size, composition and continuity of the precipitate which may influence the corrosion behavior to an extent greater than the mere presence or absence. More studies of the type Mr. Payson has conducted are needed, especially on the Type 316 specimens and on weld metals containing no molybdenum.

The authors will readily agree that this most entrancing field of austenitic stainless steels will require many hours of intensive fundamental research before all the secrets of the phase transformations are discovered. Discussions such as these provide a forum for the exchange of ideas which should contribute their part to the discovery of facts which will eventually be valuable to industry.

Electrodes for Spot Welding Galvanized Steel

Influence of electrode tip shape and material in spot welding galvanized steel. Relative merits and machine settings for each type are discussed

by Harry B. Spore

PREFACE

THIS paper has been prepared in an attempt to present to those interested in spot welding of galvanized steel a study of the influence of electrode shape and material on the weld characteristics. An effort is made to suggest appropriate machine settings for each tip shape and to indicate the relative merit of each. This investigation was based on spot welding of 1.0- and 1.7-oz. coatings of 22-gage galvanized steel, the spot welding being performed on a 75-kva. capacity welder. This investigation is intended to be of benefit to fabricators of galvanized steel articles, presenting them with information relative to electrode tip shape and material. It also may provide other researchers with data whereby they can proceed into related investigations of spot welding. This project is one of a series of spot-welding research studies performed at the University of Texas under the guidance of Prof. M. L. Begeman.

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INTRODUCTION

Scope of the Investigation

The general purpose of this investigation was to obtain factual data concerning the influence of elec-

trode shape and material in spot welding galvanized steel. The study was divided into two parts.

Electrode Tip Shape. Electrode tip shapes customarily used in industry for spot welding galvanized steel were selected. Using these tips, all having the same basic chemical and physical properties, a series of welds were made with each tip covering a selected range of conditions: Pressure, weld time and welding current were varied. The degree of flashing and the sticking of electrode tips to the galvanized sheets were noted and then the indentation, disturbance of the zinc coating and tensile strength of each weld were recorded. From this data it was possible to discuss the relative merits of each tip shape and to recommend a general range of machine settings for spot welding the material used in this study.

Electrode Tip Material. The purpose of the second phase of this investigation was to determine what difference, if any, in the weld quality was obtained by using R.W.M.A. Class I or Class II electrode tips with the various tip shapes. These two materials differed in their physical properties; the R.W.M.A. Class I having the highest electrical and thermal conductivities.

Electrode tips of both R.W.M.A. classes were obtained from the Mallory Co. and the Ampco Metal Co. This furnished a measure of the accuracy of the results obtained since the physical properties of electrode tips of a certain class are essentially the same. Thus the electrode tips of a definite shape and class manufactured by the Mallory Co. should yield the same weld characteristics as the corresponding tips made by the Ampco Metal Co. For these tests the tip pressure was standardized at 65 psi. on the basis of the results from the study of tip shape. Welding current and weld time were varied for each of the two materials from each company using the four electrode tip shapes, giving data for a comparison of the two materials and its correlation with the tip shape.

Description of the Equipment

Welder. An Acme alternating-current type hot spot welder was used for welding all the components studied in this investigation. The name plate data are as follows: Type, 3-18-75; Style, 80AR; volts, 220; cycles 60; primary amperes, 341; Serial No., 2390. The machine is rated at 75-kva. capacity with a 50% service demand at 250 v. The power circuit operates at 220 v., 60 cycles and the control circuit operates at 110 v., 60 cycles. The entire system uses single-phase alternating current. Figure 1 pictures the machine as it is set up in the laboratory.

Control equipment. Figure 2 shows the control and timing equipment used in conjunction with the welder. On the left side of the picture may be seen a General Electric control panel. It contains the adjustments for weld time and percent heat. The automatic control of the current and weld time depends upon the ability of thyratron tubes to accurately measure and control alternating-current cycles. In this way proper correlation between the electrical and mechanical functions of the welder is obtained.

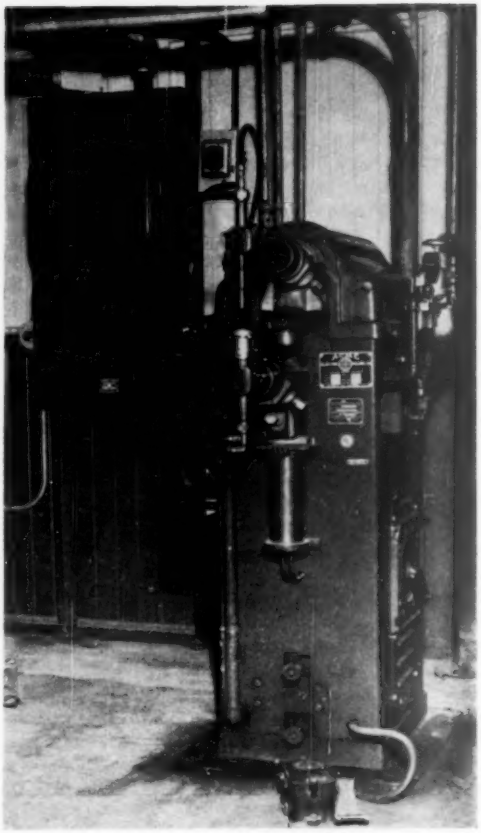

Fig. 1 Spot welder, sequence and thyratron control panels

On the right side of the picture is a General Electric

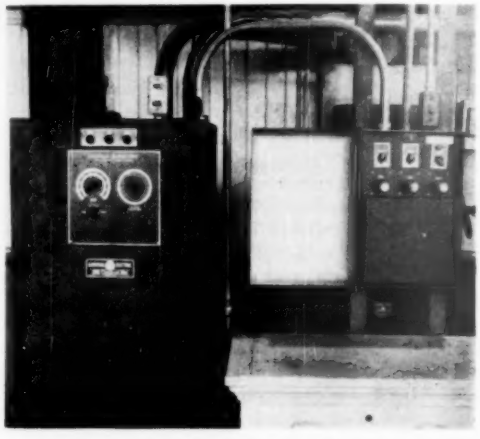

Fig. 2 Control panel

Type CR 7503-F, Number CR 7503-F116 sequence panel. It has adjustments for squeeze time, hold time and off time. The off time is not used in single spot welding such as that performed in this investigation.

Specimen Preparation and Test Equipment

The materials used in this study were sheets of 22-gage galvanized steel supplied by the American Rolling Mill Co. The zinc coating was applied by the hot dip process and two weights of coatings were used: 1.0 oz. per square foot and 1.7 oz. per square foot.

After being cut to the standard test size of 4.5 in. long and 1 in. wide, the specimen edges were ground lightly to remove any burrs, and then degreased with carbon tetrachloride.

In welding the specimens a special nonmagnetic welding jig was used to correctly position the work.

The tensile strengths of the welded specimens were checked with a Southwark-Emery Hydraulic Universal Testing Machine equipped with a Tate Emery Load Indicator. The holders used to grip the specimens were 10,000-lb. capacity Templin grips.

Weld indentation was measured accurately to one-thousandths of an inch by means of a Federal Model 49 P-409-R1, Serial Y-4539, indicating outside calipers.

EXPERIMENTAL PROCEDURE

As outlined previously, this investigation was divided into two parts; influence of electrode tip shape, and electrode tip material in spot welding galvanized steel.

Electrode Tip Shape

It was felt that the electrode tip shape was the most logical subject to be studied first, thus giving results from which the second phase of the investigation could be greatly simplified. The following electrode tips furnished by the P. R. Mallory Co. of Indianapolis, Ind., were selected as representing commercial shapes most often used in spot welding galvanized steel:

1. Pointed tip with taper shank
   (*a*) 3228 (Class II Mallory 3)
2. Dome tip with taper shank
   (*a*) 3129 (Class II Mallory 3)
3. Radius faced tips
   (*a*) 3527 (Class II Mallory 3) 2 in. radius
   (*b*) 3627 (Class II Mallory 3) 10 in. radius

The combination of welding variables selected for this phase of the investigation was as follows:

Air pressure, psi.	40	65	90	...
Weld period, cycles	3	7	11	...
Heat, %	55	70	85	100
Material coating, oz.	1.0	1.7	..	..

The procedure used for making this series of welds was as follows:

With the air pressure gage set at 40 psi., the weld time was set at 3 cycles, and the per cent heat was varied from 55 to 100 at intervals of 15%; for each set of conditions 3 welds were made on the 1.0- and the 1.7-oz. coated material. The above sequence of operations was repeated with weld periods of 7 and 11 cycles. Then the air pressure was increased to 65 psi. and the entire procedure was repeated. Upon completion of the 65 psi. pressure, the 90 psi. pressure was used.

Care was taken to insure clean tips at the beginning of each weld by dressing the tips lightly with a 320 grit carborundum paper. Clean tips which were refaced in a lathe were always installed at the beginning of each series of welds involving a new value of air pressure or when the pickup of zinc seemed excessive.

Several test welds were made with each new set of electrode tips or with each new machine setting to properly condition the electrode tips and make sure the spot welder was functioning properly. Welds were made by placing the two pieces in the welding jig, turning the test switch to the "on" position, and depressing the floor switch through its first and second stages. Ample time was allowed to elapse between successive welds to permit the electrode tips to return to a cool temperature.

Electrode Tip Material

As a result of the first phase of the investigation, it was decided to use an intermediate pressure of 65 psi, and a low weld time of 3 cycles in studying the effect of electrode tip material. Electrode tips of R.W.M.A. Class I and Class II were obtained from the Mallory Co. and the Ampco Metal Co. To investigate the possibility of one material being best suited to a particular tip shape, each tip shape was included. The electrode tips used are as follows:

Ampco Co. tips:

1. Pointed tip with taper shank.
   (*a*) WA 128 (Class I Ampcoloy No. 99)
   (*b*) WA 228 (Class II Ampcoloy No. 97)
2. Dome tip with tapered shank.
   (*a*) WB 128 (Class I Ampcoloy No. 99)
   (*b*) WB 228 (Class II Ampcoloy No. 97)
3. Radius faced tip.
   (*a*) WR 1210-2 (Class I Ampcoloy No. 99)
   (*b*) WR 2210-2 (Class II Ampcoloy No. 97)
   (*c*) WR 1210-10 (Class I Ampcoloy No. 99)
   (*d*) WR 2210-10 (Class II Ampcoloy No. 97)

Mallory Co. tips:

1. Pointed tip with taper shank.
   (*a*) 1228 (Class I Elkaloy A)
   (*b*) 3228 (Class II Mallory 3)
2. Dome tip with taper shank.
   (*a*) 1129 (Class I Elkaloy A)
   (*b*) 3129 (Class II Mallory 3)

3. Radius faced tip.
   (*a*) 1527 (Class I Elkaloy A), 2 in. radius
   (*b*) 3527 (Class II Mallory 3), 2 in. radius
   (*c*) 1627 (Class I Elkaloy A), 10 in. radius
   (*d*) 3627 (Class II Mallory 3), 10 in. radius

As a matter of interest, a series of welds were made with Mallory "3" flat tips and 6-in. radius tips in addition to those listed above.

The study of electrode tip shape further brought out the fact that the 1.0- and 1.7-oz. coated materials followed a similar trend, so it was deemed advisable to use, in the interest of simplicity, only the 1.0-oz. coated material in the study of electrode tip material.

INTERPRETATION OF EXPERIMENTAL RESULTS

General

The initial phase of the interpretation of experimental results represents an effort to show by the use of composite curves the general effect of the major variables on the physical properties of the weld using each of the four electrode tip shapes. These results combined with factors such as flashing, disturbance of the zinc coating, sticking of electrode tips and types of failure yield a comparison of the four electrode tip shapes and the optimum machine settings for each.

The second part of the interpretation of experimental results utilizes data for a comparison of R.W.M.A. Class I and Class II electrode tip materials. Curves were plotted showing the variation of weld strength and indentation with welding current for each of the four electrode tip materials with each electrode tip shape. With these curves certain conclusions were drawn as to the influence of tip material and the consistency of results obtained in spot welding hot-dipped galvanized steel.

Study of Electrode Tip Shape

The Effect of Tip Pressures on Weld Strength and Indentation. The composite curve of Fig. 3 illustrates the effect of tip pressures on weld strength at various welding currents for all weld periods for the 2-in. radius tip. This set of curves represents the general trend obtained with each shape tip and shows that the tip pressure is a rather unimportant item between the limits of 40 and 90 psi.

The composite curve of Fig. 4 is a representative curve showing the effect of tip pressure on indentation for various welding currents for all weld periods for the 2-in. radius tips. It is noted that the values of indentation have minimum values at the mid range of tip pressures.

The Effect of Welding Current on Weld Strength and Indentation. The composite curve of Fig. 5 shows the effect of welding current on weld strength at various weld periods for all tip pressures. Notice that the

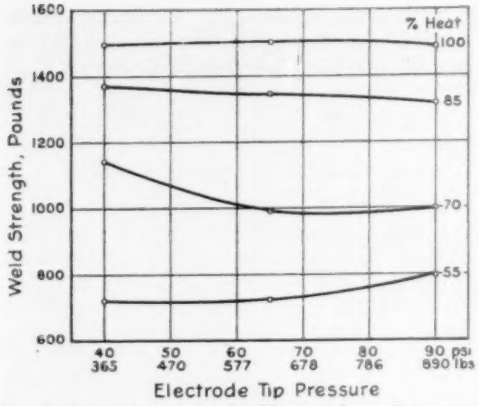

Fig. 3 Composite curves of weld strength vs. tip pressure at various welding currents for all weld periods, 2 in. radius

3-cycle curve has a more general parabolic form than the 7- and 11-cycle curves.

The curves for each of the four shapes of tips had

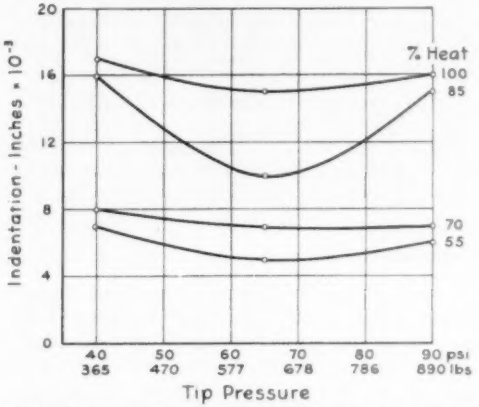

Fig. 4 Composite curves of indentation vs. tip pressure at various welding currents for all weld periods, 2 in. radius

rising characteristics, although it would not be possible to say that any of them show weld strength increasing linearly with weld current. The concentration of current for the pointed tips at 100% heat and 11-cycle weld time was so great that the electrodes were forced completely through the specimen and the tips welded themselves together. Molten pieces of metal were thrown a distance of 50 ft. from the machine. This clearly showed the fact that excessive currents could not be used, even at low weld times with any type of electrode tip, such as the pointed or dome tip which choked the current down to a very small area. Flashing and expulsion of the zinc coating were noted for high values of welding current with each value of weld time for the pointed and dome tips. This makes it

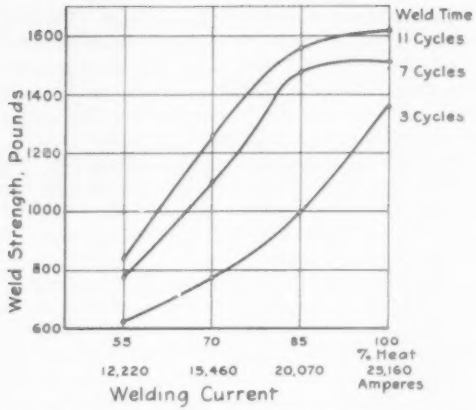

Fig. 5 Composite curves of weld strength vs. welding current at various weld periods for all tip pressures, 2 in. radius

mandatory to use only up to moderate welding currents when welding 22-gage galvanized steel with these tips. A value of 70% heat yielded an acceptable weld for both the 1.0- and 1.7-oz. coatings and an 85% heat resulted in an undesirable weld with zinc expulsion, flashing and exposing of the base metal. Thus the optimum percent heat for the pointed and dome tips lies between 70 and 85%.

Higher weld currents are possible when using the 2- and 10-in. radius electrode tips because the concentration of current is not so great and the boiling of zinc from under the tips will be less. Flashing was noted when using maximum welding current and 7 or 11 cycles well time with the 2-in. radius tips. However these deterimental effects were not noticeable with the 3-cycle weld period. It is then known that the optimum percent heat must be between the limits of 85 and 100%. The 10-in. radius tips yielded no observed flashing or expulsion of zinc for any condition, leading

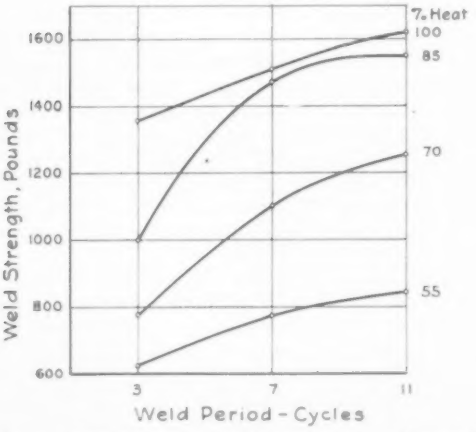

Fig. 6 Composite curves of weld strength vs. weld period at various welding currents for all tip pressures, 2 in. radius

to the belief that the capacity of this welder was insufficient to exceed the permissible welding current for these tips at an 11-cycle weld period.

The data obtained showed that excessive indentation values were obtained at high welding currents for the pointed and dome-shaped tips, further eliminating the possibility of using these tips at 85 and 100% heats. Excessive indentation was not obtained with the 2- and 10-in. radius tips in any case.

The Effect of Weld Time on Weld Strength. The typical composite curve of Fig. 6 shows the effect of weld time upon weld strength at various welding currents for all tip pressures for the 2-in. radius tips. The curves show a general increasing trend as weld times advanced from 3 to 11 cycles.

As far as weld strength alone is concerned, it appears that a weld period of 11 cycles would be optimum for each shape of tip. Reference though to the welding data shows that excessive flashing, sticking and zinc expulsion, results when using the pointed, dome and 2-in. radius tips, with a 7 or 11 cycles weld time, and enough current to secure a weld of acceptable strength. The optimum weld times for these three tips have values between 3 and 7 cycles.

An 11-cycle weld time with the 10-in. radius tips yielded welds of acceptable quality at 100% heat, with no flashing. This is believed to be very nearly the optimum condition for this tip with the capacity spot welder used. With larger capacity spot welders, it might prove more beneficial to use higher currents and a 7-cycle weld time.

The 6-in. radius tips yielded undesirable welds at 7 cycles weld time, but were satisfactory at 3 cycles and 100% heat, giving an optimum weld time between 3 and 7 cycles.

Study of Electrode Tip Material

The Effect of Tip Material on Weld Strength. Figure 7 shows curves indicating the variation of weld strength with percent heat for the four electrode tip materials with the pointed electrode tips. Ampcoloy 99 and Elkaloy A electrode tips, represent R.W.M.A. Class I materials and have practically identical physical, chemical and mechanical properties; Ampcoloy 97 and Mallory 3 represent R.W.M.A. Class II materials. This fact yields a basis for a discussion of the accuracy of the results obtained in this phase of the investigation, because theoretically the curves for the same R.W.M.A. class material should almost coincide. Reference to the curves shows that in most cases the values of results obtained, using materials of one class, vary as much as results of different materials. Extreme care was taken in preparing, welding and testing the specimens although some small error inevitably would be incurred. It is believed that the variation in thickness of the zinc coating caused the greatest error. It is not possible to indicate from these curves just which of the two materials would be best suited for use with a definite shaped electrode tip in spot welding galvanized steel.

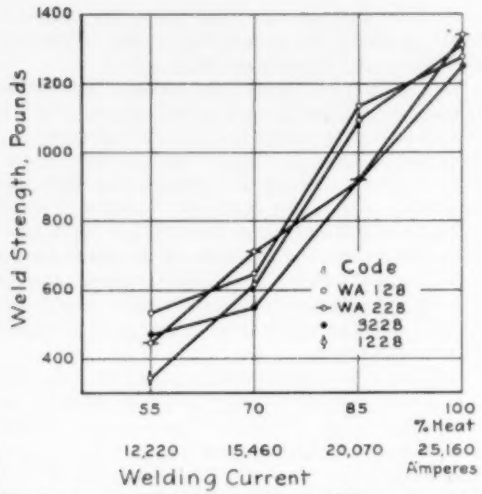

Fig. 7 Curves of weld strength vs. welding current for various tip materials, pointed tip

CONCLUSIONS

General

From the composite curves previously discussed, certain conclusions as to the influence of electrode tip shape in spot welding of 22-gage galvanized steel were obtained. Any comparison of the various shaped tips must be made under the assumption that excessive disturbance of the zinc coating would be objectionable. It must also be realized that all results presented here represent only data obtainable within the capacity of one particular spot welder. The 6-in., 10-in. and flat tips might possibly yield better results when used with larger machines.

Suggested Optimum Machine Settings

The exact settings of weld time and welding current needed will vary with the material thickness, coating thickness and method of applying the coating; so the following tabulation is included to show the range of variables considered optimum for materials spot welded during this study.

Tip shape	*Weld time cycles*	*Heat, %*	*Tip pressure psi.*
Pointed	3–7	70–85	65
Dome	3–7	70–85	65
2-in. radius	3–7	85–100	65
6-in. radius	3–7	100	65
10-in. radius	11	100	65
Flat	11	100	65

Relative Merits of the Tip Shapes Studied. The 2-in. radius tips yielded the most satisfactory results followed closely by the 6- and 10-in. radius tips in that order. The 10-in. radius tips yielded best results at 11 cycles weld time, whereas, the 2- and 6-in. tips had only a 3–7 cycle weld time for optimum conditions.

The author agrees, with most authorities on the subject, that a low weld time is most desirable in spot welding galvanized steel to minimize zinc expulsion. It is then concluded that the 2-in. radius tips represent the optimum tip shape.

The pointed and dome tips were found to be unsatisfactory in this investigation. This was chiefly due to the small contact area at the tip faces which choked down the current and resulted in flashing and excessive indentation. As a further disadvantage, these two tips are difficult to reface accurately and require considerable time for accurate alignment. The radius faced tips are essentially self-aligning and are easily machined and refaced.

The flat tips are undesirable with machines of the capacity used in this study, and it is questionable as to their desirability in spot welding galvanized steel. Actually, they may be considered as a variation of the pointed or dome tips, only with more contact surface. Accurate alignment is necessary and no advantages are apparent.

Effect of Material Coating Thickness

Results indicate that a slightly larger welding current or weld time is necessary with the 1.7-oz. coated material than with the 1.0-oz. coating, to secure welds of approximately the same strength. In welding materials of the two coatings, with the same machine settings, the tendency for flashing is less with the heavier zinc coating, but the strength is less also. However indentation will be greater with the heavier coating for welds of comparable strength. The general range of conditions suggested as optimum in this study includes the two coatings of material.

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Evaluating Notch Toughness

Meaning of the transitional behavior for the various types of specimens. Actual ship behavior is best evaluated by consideration of low levels of energy absorption, and an evaluation can be readily obtained from the keyhole or V-notch charpy impact values

by R. W. Vanderbeck and M. Gensamer

INTRODUCTION

IN THE effort to understand the brittle behavior in structures of apparently ductile steel, many tests have been performed over a range of temperatures with various types of notched specimens. The purpose of these tests has been to obtain an indication of how the steels will perform at various temperatures in service, i.e., whether they will tend to resist cracking or will fail with the characteristic cleavage type fracture. Because of a justifiable reluctance to depend upon small specimens when large structures are involved some very large specimens have been tested, such as centrally notched wide plates,[1, 2] a number of which were as wide as 72 in. Because of their size and the severity of their notch, it has generally been the belief that tests of such specimens were indicative of the behavior of the steels in service, particularly ship service. But there is reason to believe that this confidence is not wholly justified.

In all of these tests the change in some characteristic such as energy absorption or fracture appearance has been measured at various temperatures. When the temperature range over which this change occurs is relatively narrow it has been called the transition temperature range. Some temperature within this range, usually at its middle, has been called the transition temperature. In comparing the results obtained with various notched specimens, considerable confusion still exists because of the use of different criteria for the selection of transition temperatures. It has recently been shown that a number of the notched test specimens exhibit two transition temperatures, called the ductility transition and the fracture transition.[3] The criterion which is used to evaluate the test results will determine which of these transitions is measured. Therefore, if different criteria are used to select the transition temperatures for different specimens, the results may not be comparable. When the same or related criteria are used, some of the discrepancies disappear, as will be shown. However, certain anomalies still exist which have not yet been satisfactorily explained. For example, the Charpy impact transition temperatures of the so-called Navy project steels correlate poorly with the transition temperatures obtained from the 72- and 12-in. wide plate tests.[4]

Of more concern is the fact that the observed transition temperatures of the 72- and 12-in. plate specimens for the types of steel commonly used for ship plate during the war are obviously too high to correlate with experience.

The purposes of this paper are to explain the meaning of the transitional behavior for the various types of specimens, and, with this as a background, to explain the reason for the anomalies in behavior mentioned above. It is also the purpose to state the reasons for believing that actual ship behavior is best evaluated by consideration of low levels of energy absorption rather than by any particular transition temperature, that the fracture transition is not a deciding factor in ship behavior, that the ductility transition temperature does show promise of correlating with service performance, that the results of the large centrally notched plate test, as usually interpreted, do not evaluate satisfactorily the behavior of steel in structures like ships, and that either the keyhole or V-notch Charpy impact specimen is satisfactory for evaluating performance.

FRACTURE AND DUCTILITY TRANSITIONS

Although it is generally appreciated that the transition temperature range of a steel depends upon the test and the criterion, the existence of two kinds of transitions is not widely realized even now, as is evidenced by the interpretations of certain test results. Transition temperatures based upon energy absorption in one type of specimen have been compared with those

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based upon fracture appearance in another, and failure to obtain correlation has been considered sufficient evidence to discredit one or the other test specimen as a suitable means of evaluating notch toughness.

In notched test specimens a change in fracture appearance from a fibrous (shear mode) to a granular (cleavage mode) fracture occurs over a certain temperature range as the testing temperature is lowered. The temperature at some arbitrary point within this temperature range has been called the fracture transition temperature. A drop in total energy absorption also occurs over the fracture transition range, but in many types of test specimens the energy absorbed at the temperature at which predominantly granular fracture is obtained is still appreciable. In this event, as the temperature is lowered still further, the energy absorbed continues to decrease. For some specimens and for some steels, a point is reached at which the energy absorbed drops suddenly to an extremely low value. This latter drop in energy, when it occurs, may be called the transition to brittle behavior, or, for simplicity, the ductility transition. Stout and McGeady[2, 5] have applied this term to the transition temperature based upon contraction at the base of the notch, which occurs simultaneously with the transition to brittle behavior.

A performance curve showing both a fracture transition and a ductility transition might look like the solid curve sketched in Fig. 1. The drop in energy at T_1 is associated with the change in fracture appearance which occurs at this temperature. The drop at T_2 represents the transition to brittle behavior. The dotted curve of Fig. 1 represents an instance in which no sharp ductility transition is obtained as for V-notched Charpy specimens. In this case, the evaluation of performance would have to be based upon some arbitrary low level of energy.

In experiments conducted by Osborn and associates[6] on Penn State and Lehigh notched bend tests and on Navy tear tests, it was observed that the ductility transition corresponded with a change in fracture appearance of a small zone at the base of the notch. The ductility transition is thus actually a fracture transition of the material directly beneath the notch.

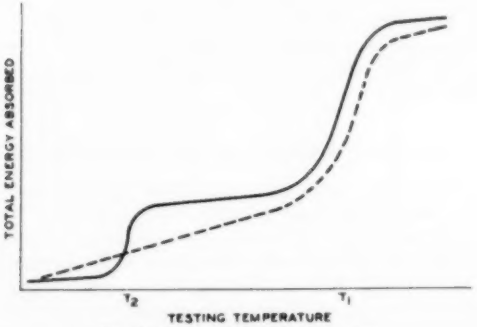

Fig. 1 Types of transition curves

Because of this observation, the fracture transition should not be defined in these tests as the temperature at which the fracture appearance changes from totally fibrous to totally granular. Instead, it is the temperature (or temperature range) at which the fracture appearance changes rather abruptly from totally fibrous to predominantly granular, with only a small area below the notch failing by shear.

The temperature at which the ductility transition occurs is very much dependent upon notch geometry, as might be expected. As the notch is made sharper and deeper, the strains are more localized and the degree of triaxiality of the state of stress is greater, both leading to higher ductility transition temperatures. On the other hand, the fracture transition temperature is dependent upon the conditions existing at the base of a crack which forms during the initial stages of testing. A crack of sufficient depth has effectively the same sharpness regardless of the original notch dimensions, and one would therefore expect the fracture transition temperature to be relatively insensitive to notch geometry, which is indeed the case. In other words, specimens with different size notches may show widely different ductility transitions, and yet show about the same fracture transition temperature. The best proof of this behavior may be found in the experiments of Stout and McGeady.[2]

It not only is important which criterion is used to determine the transition temperature, but also, if strain is used as the criterion, where that strain is measured. For example, suppose that contraction of width of the specimen were selected as the criterion of notch toughness, as has often been done. Osborn, *et al.*,[6] show that, if contraction is measured on the Penn State Schnadt-type notched slow-bend test specimen at the base of the notch, a different curve is obtained than if the contraction is measured at the drill hole at the back of the specimen. This is illustrated in Fig. 2 for rimmed steel made to A.S.T.M. Specification A-70. Measurements at the notch show the

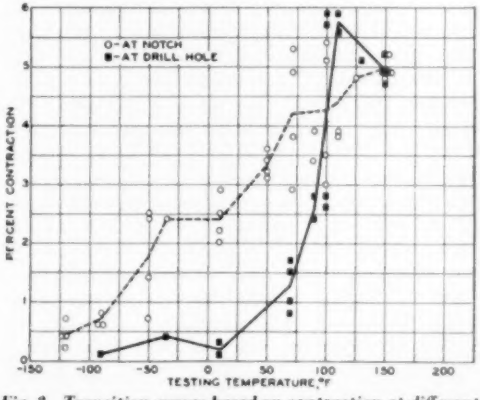

Fig. 2 Transition curves based on contraction at different locations on Penn State, Schnadt-type, bend-test specimen (after Osborn, et al.)

ductility transition occurring at about −75° F. At this temperature, however, the back of the specimen has contracted very little. Only as the crack which forms during testing extends does appreciable deformation take place at the drill hole. Contraction at the drill hole, therefore, is associated with extension of the crack and is a measure of the fracture transition temperature as Osborn, *et al.*, have shown. The same considerations apply to the Navy tear test and other types of specimens.

In the appendix to this paper transitional behavior has been discussed in terms of flow and fracture curves. The analysis may be helpful in explaining why the abrupt transition in behavior takes place and why two such transitions are present.

EFFECT OF STRAIN ON BOTH TRANSITIONS

Numerous Charpy keyhole-notched impact tests on strained and unstrained specimens of various steels, performed by the Carnegie-Illinois Steel Corp., have all shown that straining raises the temperature of the ductility transition. Moreover, the transition is raised more for some steels than for others. Such steels are considered to be more strain sensitive. The fracture appearance has also been observed in all cases, and fracture transitions for this type of test have been selected at 50% fibrous fracture. Whereas the fracture transition on as-rolled material may occur as much as 100° F. above the ductility transition, the fracture transition on material strained 10% by cold rolling is often the same as or only slightly above the ductility transition. Stated somewhat differently, straining raises the ductility transition considerably and the fracture transition very little or not at all.

The same conclusions may be drawn from results published by Osborn, *et al.*,[6] on Navy tear, Penn State Schnadt-type notch bend and Lehigh bend tests on both unstrained and strained materials. Transition curves based upon some of their results have been drawn in Fig. 3. For both types of bend test (just the Penn State bend is shown), the fracture transition increases little or not at all with 10% strain. In these cases, the ductility transition (based upon about 1% contraction at the base of the notch) of the strained material is below the fracture transition of the as-rolled plate. In the Navy tear test, however, straining has raised the fracture transition considerably. The circumstance that in the tear test the fracture transition is raised by straining is associated with the movement of the ductility transition, as measured by contraction, to temperatures above the fracture transition temperature of the unstrained material. It is obviously impossible to have the fracture transition temperature below the ductility transition temperature for this would involve the association of shear-type (high energy) fractures with low energy absorption. The only alternative is for the fracture transition of the strained material to take place over a temperature range at least as high as that of the ductility transition range.

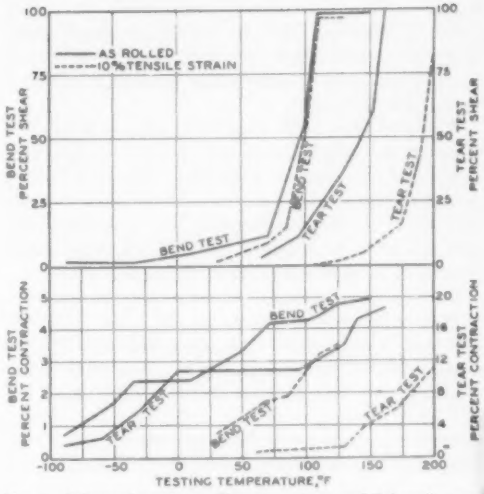

Fig. 3 Effect of strain on Navy tear test and Schnadt-type bend-test transition curves (after Osborn, et al.)

Therefore, straining will raise the fracture transition significantly only if the straining serves to raise the ductility transition temperature above the fracture transition temperature of the unstrained material. In material which has been strained sufficiently, the ductility and fracture transitions occur at very nearly the same temperatures.

THE MASKING OF THE DUCTILITY TRANSITION IN WIDE PLATE TESTS

In studying the brittle behavior of steel in ships and similar structures, it has become the practice among certain investigators to judge the merits of each type of test specimen on the basis of whether or not transition temperatures obtained with it correlate with transition temperatures obtained with the centrally notched wide plate tensile specimens. The transition temperatures of these wide plate specimens, which were used in the program sponsored by the Ship Structure Committee, were based upon a drop in energy absorption. The specimens ranged in size from 12 to 108 in. wide, and, because of their size and notch severity, their behavior was thought to represent closely the behavior of a ship in actual service. It is quite doubtful, however, that such is the case.

In the wide plate tests[1, 2] typical semikilled, open-hearth, ship-plate steels had transition temperatures of about 35° F., whereas there were some other steels which had transition temperatures as high as 100° F. Much steel of the types having the higher transition temperatures certainly went into ships, yet the Board of Inquiry's investigation of merchant vessel failures[7] has shown that only at temperatures below freezing did the fractures per ship month for vessels in port show a significant increase, and for service in heavy

seas only one serious failure (Class 1 casualty) occurred above 62° F. from November 1942 to March 1946. It certainly seems, therefore, that behavior in service is considerably more satisfactory than that indicated by the wide plate tests.

With the 72-in. wide plate specimens, a large drop in energy absorption occurred at the same temperature as that of the fracture transition. In the following paragraphs an attempt will be made to show that the large drop in energy absorption was associated only with the fracture transition and that ductility transitions were not determined for the wide plate tests.

In the wide plate tests, the contraction in thickness of the specimen may be considerable, even when the specimen breaks with a cleavage failure.[8] Typical examples for 72-in. wide plates of the C steel (semi-killed, 0.24 C, 0.48 Mn) are listed in Table 1.

Table 1—Per Cent Thickness Reduction Along Fracture Lines of 72-In. Plates

Test temperature,	*Distance from notch, in.**									
° F.	*0*	*1/8*	*1/4*	*1/2*	*1*	*2*	*4*	*8*	*16*	*26*
78	8.0	7.5	7.0	7.0	11.5	5.0	...	...	4.0	3.0
31	4.5	3.5	...	2.0	1.5	1.5	1.5	2.5	2.5	1.5

* The length of the central notch was one-fourth the width of the plate. The ends of the notch terminated in jeweler's saw cuts. The distance from one end of the notch to the edge of the plate was 27 in.

At both of the temperatures listed the specimens broke with cleavage failures, but at 78° F. the contraction along the fracture line was considerable. Even at 31° F. appreciable contraction took place close to the notch. These data are typical for all the wide plate tests regardless of plate width or type of steel.

Furthermore, strain measurements over short gage lengths of 1 in. and less reveal that just before failure the strain distribution across the width of the specimen is very nonuniform,[9] with the section just below the notch elongating considerably, but with the remainder of the plate elongating very little. A typical strain distribution at a load close to the point of failure, for a specimen which broke with a cleavage fracture, is represented in Fig. 4.

Thus, the material just below the notch can exhibit considerable ductility and yet the total energy absorbed can be relatively small. The severely strained material just below the notch constitutes only a minor portion of the whole plate. Regardless of its high energy absorption, therefore, the remainder of the plate determines to a much greater extent the total energy which will be absorbed. With a shear failure, the elongation all along the fracture line is high and the energy absorbed is correspondingly high. It is for this reason that such a big drop in energy absorption occurs as the fracture changes from shear to cleavage, and yet, there is still considerable ductility at the notch.

It would seem, therefore, that the ductility transition for most of the wide plate tests has not been determined

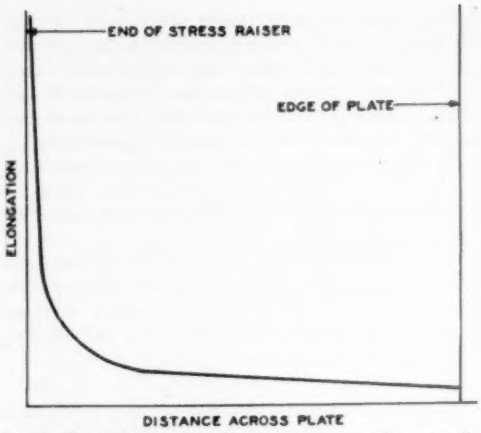

Fig. 4 Typical strain distribution across a wide centrally notched plate just before cleavage fracture

since the material under the notch still shows considerable ductility. At still lower temperatures, however, one would expect a ductility transition or at least a further drop in energy absorption, but this drop would be dwarfed by the large drop obtained in the temperature range where the fracture appearance changed. The type of curve which has been hypothesized for the wide plates might look like Curve *A* in Fig. 5. The drop in energy at the ductility transition might even be less obvious than that pictured. A smaller specimen in which the material under the notch constituted a greater part of the breaking section might indicate a performance such as that of Curve *B*.

In the smaller specimens, the behavior of the whole specimen is dependent to a much greater extent upon the behavior of material at the notch. In the bend tests, particularly, the material at the notch governs to a large extent the over-all behavior because of the

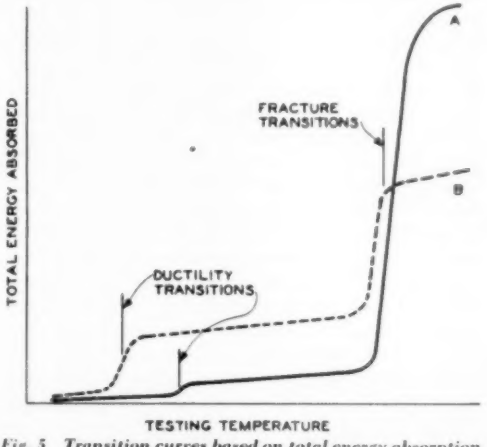

Fig. 5 Transition curves based on total energy absorption as pictured for large, centrally notched, wide plate specimens (Curve A) and for small notched specimens (Curve B)

stress distribution and the small size of the specimen. With such specimens, energy absorption or angle of bend can be used readily as a criterion of the final transition to brittle behavior. In fact, a low percentage of contraction (on the order of 1%) at the base of the notch is often used as the criterion of the ductility transition.[5, 10]

In comparing test results for small specimens with those for the wide plates, the criterion of performance which was used for both keyhole and V-notched Charpy impact specimens was energy absorption.[4] The Charpy test results for the various steels did not correlate sufficiently well (especially for the A and C steels) with the wide plate results, so impact tests were discredited. When other types of specimens were employed, however, such as the Penn State notched bend test[4, 11] and the Navy tear test,[12] fracture appearance and associated criteria were used to determine the transition temperature. By such criteria, correlation with the wide plate results was much better because fracture transitions were being compared. It would be interesting to know if fracture transitions for the impact specimens would have correlated with the wide plate fracture transitions, and if the measurement of the transitions to brittle behavior for the tear and bend tests would not have shown as poor correlation with the wide plate results as the impact tests. It would be still more interesting to know if the transitions to brittle behavior for the wide plate tests would correlate with the corresponding behavior in impact tests; a little information is available on this point and will be discussed later.

To reiterate, the characteristics of the centrally notched wide plate tests have masked the ductility transition, if a sharp transition exists, or in any event, have masked the behavior at low energy levels. The balance of this paper will be devoted to developing the thesis that behavior at low energy levels is of major importance in determining performance in service.

DIFFERENCES IN BEHAVIOR BETWEEN WIDE PLATE SPECIMENS AND A SHIP

There are important differences between the behavior of a wide plate specimen and that of a ship or similar structure. These differences are believed to be concerned mainly with the sharpness of the notch. On a ship the sharpness of many of the notches or stress-raisers is much greater than the sharpness of the notch initially present in the wide plate specimens. The notches in a ship are frequently sharp cracks, perhaps minute, resulting from or associated with such things as defective welds and edges flame cut during fabrication, and they may even be fatigue cracks.

Results obtained by Thomas and Windenburg[13] on 12-in. wide centrally notched plate specimens clearly show that increasing the sharpness of the notch lowers the average stress at which fracture occurs. Some of these results are shown in Table 2 for a central notch one-fourth the width of the plate.

Table 2—Effect of Notch Diameter on Fracture Stress

Notch diameter, in.	*Temperature, ° F.*	*Average stress at fracture, psi.*
JSC*	38	37,800
0.08	38	47,000
0.25	0	52,800
0.25	73	52,100
0.50	38	57,600
0.75	38	58,000

* Jeweler's saw cut. The other notches terminated in holes of the indicated diameter.

NOTE: All fractures were reported as cleavage.

These results indicate that the average fracture stress in a specimen with a very sharp notch would be considerably less than 37,000 psi. The 72-in. wide plate tests with the jeweler's saw cuts as notches fractured at a nominal stress of about 30,000 psi., but on a ship the nominal stress to produce fracture is believed to be appreciably lower, on the order of 10,000 psi. The S.S. *Schenectady* failed at dock under known loading conditions at 9900 psi.[7] Calculations place the maximum stress likely to be encountered at sea with severe "hogging" at 13,750 psi.[7] That failures occur at these low stresses is clear evidence that the stress concentration aboard ship is more severe than in the wide plate tests.

In the various notched test specimens including the wide plates, it was noticed that a small zone of shear fracture directly beneath the notch usually persisted at temperatures considerably below the fracture transition temperature. Only at much lower temperatures did this small zone change from shear to cleavage failure (the ductility transition). Obviously, this small zone of shear failure appeared because the initial notch sharpness differed from the sharpness of the crack which was formed. The initial milder notch geometry favored a shear failure. Once the shear crack formed, the more severe notch geometry favored cleavage failure. With a sufficiently sharp notch shear failure directly under the notch would not be expected to occur much below the fracture transition temperature.

That this behavior actually takes place when a sharp crack is present was substantiated by the following experiment which was performed for Carnegie-Illinois Steel Corp. at Pennsylvania State College. V-notch Charpy impact specimens with the notches normal to the original plate surface were flexed so as to form a small fatigue crack at the base of the notch after the manner of Zeno and Low.[14] The material was a low-carbon, low-alloy, hot-rolled steel. Specimens without the fatigue crack were also prepared. The impact results at various temperatures for both types of specimens are presented in Fig. 6.

As the temperature was raised from −20 to 120° F. in the fatigue-notched specimen, the deformation at the side and back of the specimen increased, and such shear failure as was present took place along these edges rather than under the notch, as is seen in the specimen tested at 68° F. in Fig. 7. Shear failure did not appear

at the notch until a temperature of 120° F. was reached. Above 120° F. the amount of shear fracture under the notch and in the remainder of the specimen increased rapidly. If the fracture transition temperature were arbitrarily based upon 50% shear fracture, it would

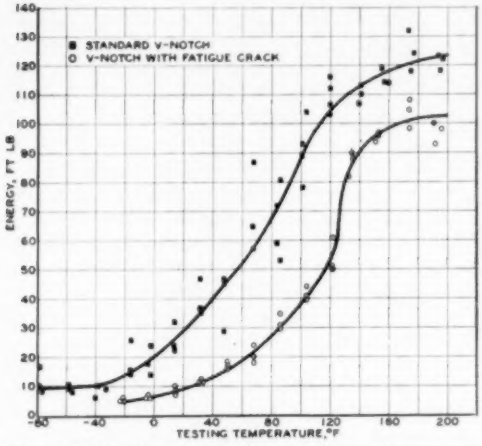

Fig. 6 Effect of notch severity on Charpy impact performance

occur at 120° F. In this instance, therefore, shear fracture at the notch made its appearance at the same temperature as that of the fracture transition. In the standard V-notched impact specimens, a small amount of shear failure appeared at the sides and back of the specimen as the temperature was raised to about 40° F., at which temperature shear failure at the notch became perceptible. The fracture transition (at 50% shear) occurred at 100° F. In this instance, shear fracture at the notch occurred well below the fracture transition temperature. It will be seen, therefore, that a sharp crack favors the formation of a cleavage fracture rather than a small amount of shear followed by cleavage.

Earlier in this paper, the ductility transition was associated with the transition to brittle behavior and also with the change in fracture appearance of a small area at the base of the notch. This latter change, however, occurred at the 50 ft.-lb. level at 120° F. in the fatigue-notched specimens, and the transition to brittle behavior occurred gradually from 120 to −20° F. It is surprising to note that even the standard V-notched Charpy specimens were characterized by similar behavior. The fracture at the base of the notch changed in appearance at the 40 ft.-lb. level at 40° F., and the transition to brittle behavior took place gradually from 40 to −40° F. A ductility transition as it has been described earlier for the slow bend and tear tests did not occur with these two types of impact specimens since conditions of both brittle behavior and change in fracture appearance at the notch were not simultaneously fulfilled. In other tests the ductility transition has been associated with an abrupt change in

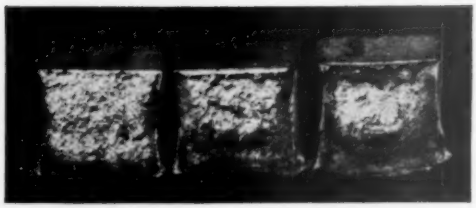

Fig. 7 Fracture appearance of broken V-notch impact specimens with fatigue crack. Testing temperature and energy absorbed are, left to right: 68° F., 24 ft.-lb.; 122° F., 51 ft.-lb.; 133° F., 82 ft.-lb.

energy absorption; but in these tests, the change from tough to brittle behavior took place gradually over a wide temperature range. This behavior as exhibited by specimens with sharp cracks is believed to describe the behavior exhibited by a ship better than the wide plate tests.

Unfortunately, Zeno and Low,[14] while working on ship plate, did not report the details of changes in fracture appearance. Moreover, their specimens were notched parallel to the plate surface which alters the type of curve obtained.

IMPORTANCE OF LOW ENERGY LEVELS RATHER THAN TRANSITIONS

In the Liberty ships that failed, the calculated nominal stress in the crown of the deck at time of fracture varied from 3315 to 12,200 psi.[7] This may be compared with the 30,000 psi. required to fracture the 72-in. wide plate specimens. The available stored elastic energy in a specimen of sufficient length is proportional to the square of the stress, which means that the elastic energy available in the wide plate specimen is from 6 to 80 times as great as that available in a ship. Since this relatively small amount of available energy in a ship has in some instances been enough to bring about failure, it is necessary to consider low energy levels in any evaluation.

Fractured plates from ships which have failed in service usually exhibit small reductions in thickness, on the order of 1 to 3%, and it would be logical to associate the behavior of these fractured plates with low energy absorption and thus to look for similar performance at low energy levels in the impact or any other test.

Moreover, sharp cracks, such as are associated with defective welds, are said to be present in a ship, and consideration of specimens with sharp cracks has indicated that no sharp ductility transition to brittle behavior occurs; instead, a gradual transition to brittle behavior takes place.

Taking all three of these factors into consideration, it would seem that it would be better to judge the performance of a ship by considering the temperature at some arbitrary low energy level for a sharply notched specimen, rather than considering some particular transition temperature for any one of the various tests.

The fracture characteristics and behavior at low energy levels of the Charpy specimens with a fatigue crack are believed, for the reasons previously given, to portray the manner in which failure takes place on a ship. It will be remembered, however, that the standard V-notched Charpy specimens exhibited somewhat similar behavior in that the same gradual transition to brittle behavior took place. It would be hoped, therefore, that an evaluation of the results of such specimens at low energy levels would correlate with behavior in service.

Williams and Ellinger[15] have presented data showing correlation among the results of standard V-notched Charpy impact specimens from plates which had fractured in ship service. These plates were divided into three groups: those containing the source of fracture, those through which the fracture passed and those containing the end of the fracture. V-notched Charpy impact specimens were taken from areas at least 1 in. from the fractured edges, and transition temperature curves were determined. At the temperature of ship failure, plates in which the fracture originated absorbed an average of about 6 ft.-lb. of energy (range 3.2 to 11.4), those through which the fracture passed absorbed about 8.5 ft.-lb. (range 3.8 to 14.7), and those in which the fracture ended absorbed about 12 ft.-lb. (range 6.0 to 21.4). Although the differences in these average energy absorption values are relatively small, it should be kept in mind that they represent appreciable differences in temperature because of the gradual slope of the V-notched Charpy transition curve, particularly at low energy levels. For example, a difference of 5 ft.-lb. at low energy levels is associated with a difference of 20 to 30° F. in temperature.

These results indicate that cleavage fracture started because of insufficient notch toughness. They might also be taken to indicate that the fracture stopped because it encountered plates of higher notch toughness which would absorb a greater amount of energy. Although it is certainly possible to obtain cleavage failures in these plates at higher temperatures than those at which the fractures stopped, it may be that insufficient energy was available in the ships to propagate the fracture further. It would seem, however, that other factors enter into the arresting of the cracks, such as the greater notch toughness of certain areas of the weldment and changes in stress as the crack advances.

The V-notched Charpy test seems particularly suited to evaluating susceptibility to failure because the energy values obtained in this test at the temperature of ship failure are relatively low, signifying nearly completely brittle behavior, and this same kind of behavior is encountered in actual ship failures.

The V-notch Charpy test has not been applied extensively to plate products. The keyhole-notch impact test is considered the industry's standard and, therefore, has been used much more frequently. Fortunately, there is quite a good correlation between the ductility transition temperature for the keyhole test and the temperature at which an arbitrary low energy absorption is exhibited in the V-notch test; so that keyhole-notch Charpy tests may be used as well as the V-notch test. But before presenting the data and describing this correlation, it seems advisable to discuss briefly the role of welding.

EFFECT OF WELDING ON SHIP PERFORMANCE

It has been demonstrated in the literature that certain parts of the heat-affected zone adjacent to a weld are poorer in notch toughness than the parent metal.[16] Tests have also been performed on steel which was heated to different temperatures in order to determine roughly the effect of the heat of welding on the notch toughness of material adjacent to the weld. These tests indicated that heating to certain temperatures impaired the notch toughness of the steel.[5, 17]

The results obtained by Williams and Ellinger, however, indicate that the propagation and stopping of cracks is mainly dependent upon the properties of the parent plate, regardless of the presence of welds, for their correlations were obtained without any consideration of welding effects. A weld with its possible attendant cracks and porosity must certainly influence the initiation of cracking. Moreover, it might influence the propagation of cracking as long as the crack follows the weld or travels through the heat-affected zone. But, once the crack enters the unaffected base metal, that metal alone would determine subsequent behavior. If the base metal were sufficiently notch-tough, the crack would propagate no further. If the weld provided a path for the crack to follow directly across the structure, then the notch toughness of the weld and heat-affected zone would undoubtedly determine service performance, provided that the crack followed this path.

In the regular hatch corner[18] and modified hatch-corner tests performed at the University of California, it would seem that fracture occurred essentially adjacent to the weld and that, therefore, the heat-affected metal, rather than the unaffected parent plate, was controlling the behavior. Thus, in the various tests on high yield strength steel described by Boodberg and Parker,[19] the modified welded hatch corner tests showed fracture transition temperatures some 50° F. higher than those of the unwelded 3- and 12-in. wide notched plate tests for all of the steels investigated. This was probably caused by the fracture occurring adjacent to the weld in the hatch corner tests.

CORRELATION BETWEEN LOW ENERGY LEVELS AND DUCTILITY TRANSITIONS

The ductility transition has been described as the transition to brittle behavior and has been associated with the change in fracture appearance of a small zone directly below the notch. Some specimens do not exhibit a transition that meets these conditions, but instead exhibit a gradual drop in energy absorption below the temperature at which the zone at the base of

the notch becomes entirely cleavage. Transition temperatures, however defined, are not necessarily of any particular significance in predicting behavior in ship service. The energy level at which a crack progresses at the service temperature is believed to be of greater significance. The evidence seems to indicate that the significant energy level is quite low. Although the standard V-notched Charpy specimen does not contain a very sharp crack, results obtained by Williams and Ellinger with this specimen have been found to correlate quite well with the tendency of a crack to propagate rapidly in ship failures. The Charpy V-notched specimen does not exhibit a ductility transition, and correlation with service behavior was simply based upon low energy levels of performance.

Nevertheless, there is no apparent reason why temperatures associated with low energy levels should not correlate with ductility transition temperatures as determined by certain types of test specimens. Low performance levels would be involved in both instances. An example showing such correlation between tests of V-notched and keyhole-notched Charpy specimens follows. For the V-notched specimens, temperatures were selected which are associated with low energy levels and, for the keyhole-notched specimens, ductility transition temperatures were selected. First, the behavior of keyhole-notched specimens must be briefly described.

A typical set of impact data using the Charpy keyhole-notched specimen is shown in Fig. 8 for a steel of the ship plate type. An envelope has been drawn around the data to portray more clearly the behavior. Between -15 and $+25°$ F., a zone is obtained in which there is considerable scatter. Usually either high values (20 ft.-lb.) or low values (5 ft.-lb.) are obtained in this zone, with very few intermediate values. At temperatures above this zone the energy values are uniformly high (the specimens behave in a tough manner), while below the zone the values are uniformly low (the specimens behave in a brittle manner). The specimens that exhibit brittle behavior exhibit 100% cleavage fractures with no shear directly below the notch. The tough specimens all show definite amounts of shear fracture below the notch. This scatter zone then truly represents the ductility transition as it has been described. The transition occurs over a temperature range and the more tests that are performed the wider the range will be. Numerous examples of this same type of behavior have been given by Kahn and Imbembo.[12]

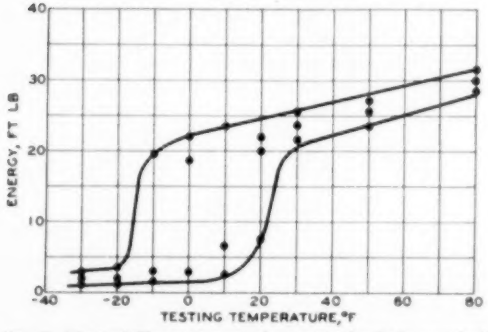

Fig. 8 Typical Charpy impact data using keyhole-notched specimens

To return to the discussion of the correlation between the ductility transition temperature in a test which exhibits one and the temperature at low energy levels in a test which does not exhibit a ductility transition, Fig. 9 shows the correlation between temperatures selected at the 10 ft.-lb. level for the V-notched Charpy specimen and ductility transition temperatures selected at the middle of the scatter zone for keyhole-notched specimens. A number of steels are represented[20, 21] including the various Navy project steels used in the ship plate investigations. Some of these latter steels have behaved in an anomalous manner, showing quite different transition temperatures when tested at different times or when different plates were tested using the same type of test specimen.[1, 11] Moreover, the testing was not always sufficiently extensive to determine the transition temperature with the accuracy desired. Despite the sampling difficulties and testing deficiencies, the correlation in Fig. 9 for the two types of Charpy specimens is quite good.

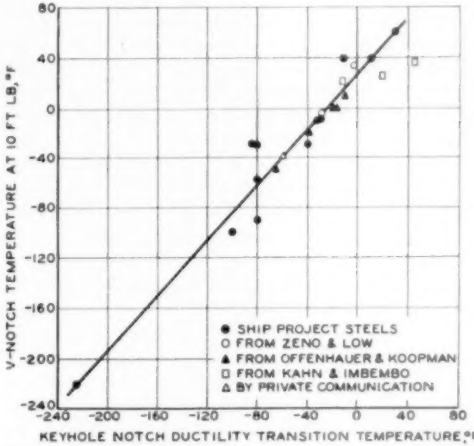

Fig. 9 Relationship between temperature at low energy level for V-notch Charpy specimens and ductility transition temperature for keyhole Charpy specimens

Thus, if the temperatures at low energy levels in the Charpy V-notched specimen should prove adequate for predicting certain types of failure, then ductility transitions in other types of specimens, such as the keyhole-notched Charpy bar, should also prove satisfactory. It is encouraging to observe the correlation between keyhole-notched and V-notched Charpy tests, and between the V-notched tests and plates in service. Keyhole-notched Charpy specimens are used extensively for testing plate products, and the relationships which have

been found for the steels investigated would tend to support the continued usage of the keyhole-notched specimen for evaluating behavior in service.

LOW ENERGY LEVELS IN WIDE PLATE TESTS

Better correlation between Charpy results and centrally notched wide plate results might be obtained if the wide plate performance were based upon the low energy portions of the transition curves rather than upon those portions which are associated with fracture transitions. This would be consistent with the notion that low energy levels in the various tests are of major importance in determining ship behavior because low unit energies are believed to be adequate to prevent the ship failures themselves.

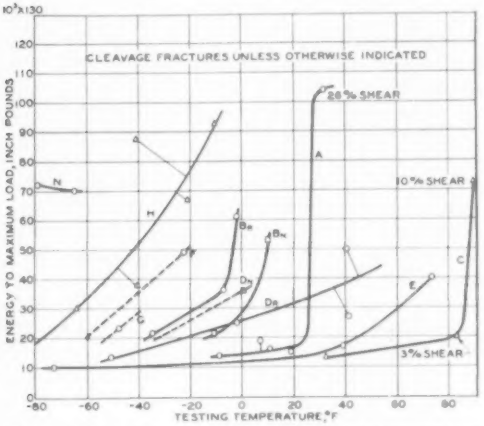

Fig. 10 Low energy portions of energy-temperature curves for centrally notched, 12-in. wide, 3/4-in. thick plates

The available data for the 12-in. wide centrally notched plate tests[1, 2] on the Navy project steels are plotted in Fig. 10. Energy to maximum load has been plotted vs. testing temperature, and only the low energy portions of the curves are shown. It will be observed that the data are incomplete at the low energy portions of most of the curves. For steels F and D_h it was necessary to extrapolate to low energy values, following in general the slopes of the other curves. Temperatures were then selected for each steel at the 20,000 in.-lb. energy level, which represents a relatively low energy level for the test specimen used. These temperatures were then compared with the temperatures obtained from V-notched Charpy transition curves at the 10 ft.-lb. level. The Charpy results were obtained from both Penn State[4] and University of Illinois[3] data.

The resulting correlation, shown in Fig. 11, between the temperatures corresponding to low energy levels in these widely different tests is quite good. Moreover, approximately the same critical temperatures were obtained for each specific steel with both types of specimens.

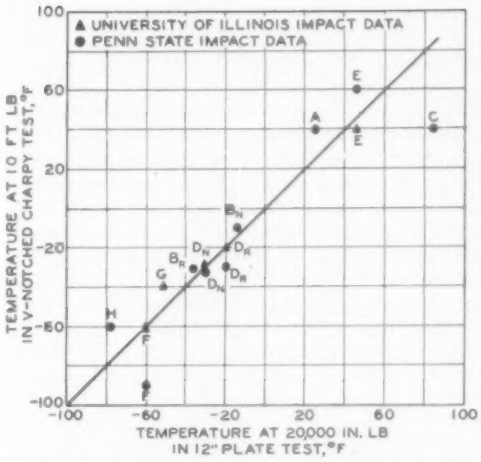
▲ UNIVERSITY OF ILLINOIS IMPACT DATA
● PENN STATE IMPACT DATA
TEMPERATURE AT 10 FT LB IN V-NOTCHED CHARPY TEST, °F
TEMPERATURE AT 20,000 IN. LB IN 12" PLATE TEST, °F

Fig. 11 Correlation between V-notch Charpy and 12-in. wide centrally notched plate tests at low energy levels

Steel C does not seem to fit this correlation, but it is believed that this can be explained. In Fig. 10 it can be seen that steel C is different from all the other steels in that it shows some shear fracture (3%) at a very low energy level. Despite this appreciable shear fracture, the energy absorbed to maximum load is only some 20,000 in.-lb. It is believed that the total energy to fracture in this instance must be appreciably greater because of the shear fracture. It would seem then that measurement of just energy to maximum load has made Steel C seem poorer in the wide plate tests than it actually is. Furthermore, subsequent tests of 12-in. wide plates at Swarthmore College[22] indicate that even the energy absorbed to maximum load is higher than that indicated in Fig. 12 for Steel C.

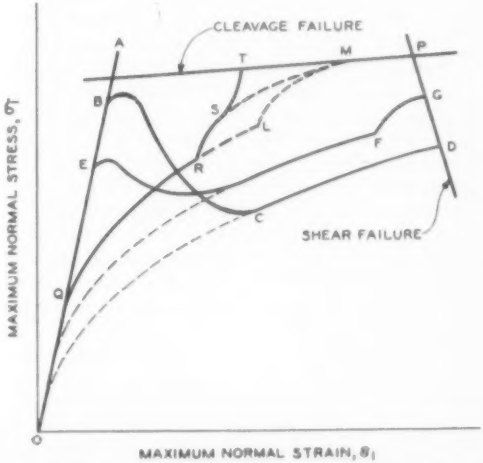

Fig. 12 Hypothetical flow and fracture curves depicting conditions leading to ductility and fracture transitions

SUMMARY AND CONCLUSIONS

The test results of various types of notched specimens have been reviewed in an attempt to clarify the meaning of these results and to establish some relationship between the test results and behavior in service. It is realized that more data would be needed to test adequately these conclusions. The aim has been to obtain the maximum information from the available data and to determine whether or not the results are consistent with the beliefs which have been expressed.

In many of the tests performed on notched specimens to evaluate notch toughness, the results have exhibited two different transition temperatures. One of these occurs at relatively high energy levels and is associated with the change from a fibrous to a predominantly granular-appearing fracture. This is called the fracture transition. The other occurs at low energy levels and at a lower temperature than the fracture transition and is associated with the change in fracture appearance of a small zone directly under the notch, and with the transition from tough to brittle behavior. This has been called the ductility transition.

Several criteria may be used to determine each transition temperature. In order to determine the transition which is desired, whether fracture or ductility, care should be excercised in the selection of such criteria and in the evaluation of test results. Failure to do so may result in apparent anomalies when the results of different types of specimens are compared.

Small amounts of plastic straining raise the ductility transition temperature considerably but have little effect on the fracture transition temperature. The fracture transition is raised if the straining is sufficient to raise the ductility transition above the fracture transition of the unstrained material. With sufficient straining, the ductility and fracture transitions occur at very nearly the same temperatures.

The centrally notched wide plate tests exhibit as much as 10% or more reduction in thickness near the notch at temperatures below the fracture transition. It seems, therefore, that the transition to brittle behavior was not determined for these specimens. Hence, it is not believed proper to compare the fracture transitions obtained from the wide plate tests with ductility transitions obtained from other specimens.

The fracture transitions obtained with the wide plate specimens occur at such high temperatures for the types of steel commonly used in ships that they do not seem to correlate with service experience. There are believed to be major differences in behavior between the wide plates and an actual structure like a ship due to differences in nominal stress and notch severity. The wide plate test characteristics are such as to emphasize the large change in energy absorption at the fracture transition temperature and to minimize the differences in behavior below this temperature.

Consideration of the behavior in a ship has led to the belief that quite low energy absorption levels are of greatest importance and that a sharp transition in behavior does not take place at these levels. Whether a plate in a ship will stop or support propagation of a sharp crack is believed to depend upon the ability of the plate to absorb at least a certain small critical amount of energy at operating temperatures. If the plate can absorb this energy, the crack will be arrested. The critical temperature, therefore, would be associated with a certain critical energy level and not necessarily with any sharp transition temperature. Indeed, tests on standard V-notched Charpy specimens and on similar specimens with a small fatigue crack at the bottom of the notch show that the absorbed energy increases gradually from low to relatively high values. No sharp transition to brittle behavior takes place with these specimens.

Williams and Ellinger have shown good correlation between the performance of V-notched impact specimens at low energy levels (about 10 ft.-lb.) and the actual behavior of ships in service. Such results support the selection of low performance levels for evaluating ship behavior.

If a low performance level is selected for evaluating the 12-in. wide plate results on the Navy project steels, a fairly good correlation is obtained between these results and Charpy V-notch results at the 10 ft.-lb. energy level.

A number of specimens, among them the keyhole Charpy specimen, do show a rather sharp ductility transition at low energy levels. It seems likely that these ductility transitions may also prove suitable for evaluating the ability to resist cracking in service. The ductility transition, rather than the fracture transition, is believed to correlate more closely with performance.

ACKNOWLEDGMENT

The authors gratefully acknowledge the suggestions of their associates in the Research and Technology Dept. of the Carnegie-Illinois Steel Corp. and wish especially to express their thanks to S. C. Snyder whose advice has been most helpful in preparing this paper.

APPENDIX

An attempt is made below to explain by means of flow and fracture curves how and why two transitions occur. To do this, different locations on the cross section of the specimen must be considered separately in order to explain how the mixtures of shear and cleavage fracture occur. Both the ductility and fracture transitions are directly associated with the percentages of shear and cleavage fracture which are obtained, as has been pointed out.

Consider a notched bend type of specimen which will produce a transition curve such as the solid curve of Fig. 1, where both transitions are sharp and clearly defined. To avoid the complicating effects of compression, the Schnadt-type of specimen will be examined. In this specimen a drilled hole at the back of the speci-

men eliminates the compression zone. It will be assumed that fracture will occur when the flow curve intersects either the curve for cleavage failure or the curve for shear failure, the type of fracture obtained depending upon which of the curves is intersected. Such hypothetical curves have been proposed by Davidenkov[23] and are shown in Fig. 12. Since ductile fracture does not generally obey a critical tensile stress condition, a single curve for shear failure probably should not be assumed.[24] The argument to follow might be presented without employing such a curve by assuming that shear failure occurs if the flow curve and the curve for cleavage failure do not intersect. The discussion will be simplified, however, if it is assumed that shear failure does take place along some such curve as that presented.

BELOW THE DUCTILITY TRANSITION

At a temperature immediately below the ductility transition, an entire cleavage fracture is obtained with practically no accompanying deformation. All points on the cross section of the specimen must, therefore, behave in an essentially elastic manner and follow a curve such as *OA* in Fig. 12. Brittle failure occurs when Curve *OA* intersects the curve for cleavage fracture.

As long as the specimen behaves elastically, the stress concentration at the base of the notch will be high. Moreover, in such regions of high stress concentration, the stress at which yielding occurs may be considerably in excess of the normal yield point. This effect has been called "elastic superstressing." Orowan[24] states that the usual upper yield point may be exceeded by a factor of 2 or 3 at the bottom of a notch.

BETWEEN THE DUCTILITY AND THE FRACTURE TRANSITIONS

Consider, now, some higher temperature at which the material at the base of the notch will start to flow and behave in a ductile manner. As flow occurs, the stress concentration will be rapidly reduced to unity.[25] The reduction in stress concentration will thus be accompanied by a decrease in the longitudinal stress at the notch surface which elastic superstressing had originally raised to a value considerably in excess of the normal yield point.

It might also be said that when flow first occurs the high stress concentration at the notch causes the material at the base of the notch to flow at a relatively high rate. This high strain rate would serve to elevate the initial portion of the flow curve. As flow continues, the reduced stress concentration would reduce the rate of flow and tend to depress the flow curve.

The flow curve, therefore, for a location at the surface of the specimen at the bottom of the notch would look like Curve *OBCD*. As soon as yielding occurs at *B*, the reduction in stress concentration and the resultant lower strain rate will start to lower the longitudinal stress until, say, it reaches Point *C*. If plastic strain has essentially eliminated the stress concentration when the curve reaches *C*, additional strain will produce the usual type of true stress-strain curve, *CD*. At *D*, the material directly at the base of the notch fails by shear.

Other parts of the cross section, however, will not follow this same stress-strain curve because of a different degree of stress concentration, triaxiality caused by the notch and the added effect of the crack which has formed at the notch bottom. Triaxial stresses exist in a notched specimen except at the surface where only biaxial stresses are present. Curve *BCD* applies only for a biaxial stress condition. Triaxial stresses serve to raise the longitudinal stress for a given strain and, hence, to raise the flow curve. There is some justification for believing that the state of stress rises to a maximum triaxiality at some short distance below the notch surface,[25] and this will be assumed in the present instance.

The flow curve of a location slightly below the notch might therefore be represented by Curve *EF* in Fig. 12. At this location there is less stress concentration and less elastic superstressing than at the surface and the material starts to flow at *E*. The decrease in stress concentration with increasing plastic flow and the presence of triaxial stresses cause Curve *EF* to assume a position such as that depicted. When the material just below the notch has flowed to Point *F*, it will be assumed that a crack has just begun to form at the surface of the notch. From Point *F* on, therefore, the sharper crack and the increasing depth of the notch probably serve to raise the flow curve somewhat so that failure finally occurs at *G*, and again it occurs by the shear mode.

For the type of specimen being considered, it is not believed that the triaxiality will increase to any extent after the crack has penetrated to a relatively small depth. Assuming this to be so, Curve *FG* will be concave downward and will soon tend to follow a path approximately parallel to the flow curve indicated for the material before the crack formed.

At a position in the bend specimen somewhat further from the notch than the location which gave the flow curve *EFG*, increased triaxiality will further raise the flow curve so that it intersects the curve for cleavage failure at some point to the left of *P*. Cleavage fracture then results. This situation is not sketched in Fig. 12; the curve would start below *E* but end between *M* and *P*.

At a location still further from the notch, no stress concentration (and no elastic superstressing) will exist; flow will therefore occur along *QR*. The formation of a crack at the notch surface then elevates the curve to *RS*. Suppose that when the flow reaches *S*, cleavage failure starts to occur at a position nearer the notch due to its flow curve intersecting the curve for cleavage failure just to the left of Point *P*. The cleavage failure starts to take place rapidly and greatly increases the strain rate. This effect may cause the flow curve to turn sharply upward along *ST* instead of continuing out to Point *M*.

It will be seen, then, that a small area under the notch fails by shear and absorbs considerable energy. Most of the specimen, however, fails by cleavage, and absorbs much less energy per unit area. The total energy absorbed would be the sum of the areas under all the curves, such as those described, for all of the different locations across the breaking section.

The transition from brittle behavior, as portrayed by Curve *OA*, to the behavior just described would be synonymous to what has been called the ductility transition. Moreover, the analysis indicates that transition from very low energy absorption to appreciably greater energy absorption would occur without any (or, at least, relatively few) values of intermediate energy absorption being obtained. This type of behavior does occur in the Charpy keyhole-notched impact test and is believed to occur in tests on other types of notched specimens although too few data are available to make a more positive assertion.

ABOVE THE FRACTURE TRANSITION

The fracture transition must now be explained. At the temperature just discussed which produced such curves at *BCD* and *QRST*, consider the location closest to the notch where the triaxiality reaches as high a value as it ever would attain. Such a location exists if, as assumed, the degree of triaxiality does not continually increase as the crack progresses, but, rather, levels off to a constant value after the crack has progressed a relatively short distance. Suppose that the flow curve of this point is represented by *QLM* (the surface of the specimen starts to crack when Point *L* is reached). No position further from the notch could then intersect the cleavage failure curve to the left of Point *M* unless increased strain rate caused it to do so, as along Curve *ST*.

It will be seen that in order to obtain a completely shear fracture in the whole specimen, the temperature must be raised sufficiently to lower Curve *QLM* so that it intersects the curve for shear failure. As soon as *QLM* intersects the curve for shear failure just below Point *P*, the energy absorbed increases abruptly to a high value, for at all locations on the specimen cross section the flow curves will intersect the shear failure curve.

The change from a relatively small amount of shear fracture to totally shear fracture represents what has been called the fracture transition. The energy absorbed increases from intermediate to much higher values with few values falling in between. Such behavior is characteristic of specimens large enough to permit a crack to develop its maximum severity before having traversed the whole specimen.

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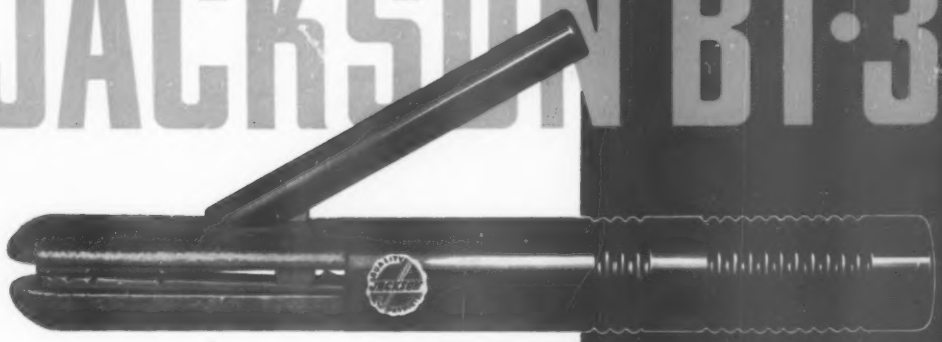

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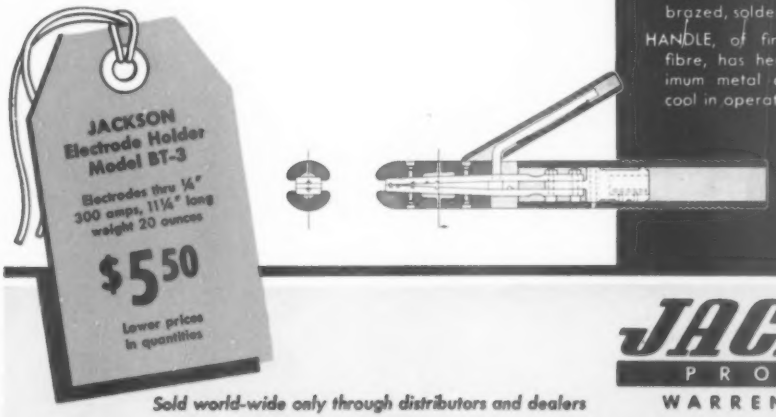

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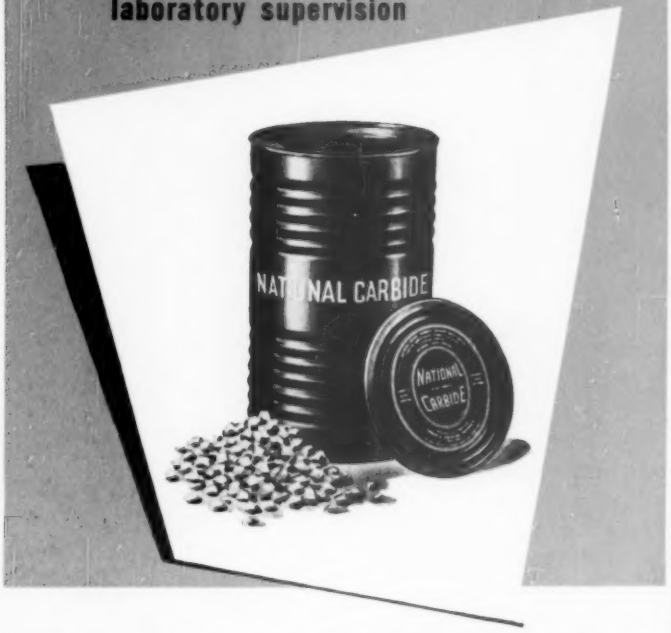

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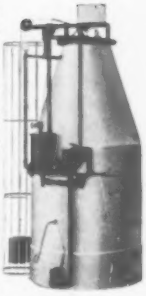

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